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ALL ABOUT SPACE™

ISSUE 135
OCTOBER 2022

Its formation and fascinating history • Observe its craters, seas and mountains

COMPLETE GUIDE TO THE MOON

• From Apollo to Artemis, our exploration of our natural satellite

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Leslie Kean

WELCOME

ISSUE 135

It may have been scrubbed multiple times since August, plagued by cracks between the liquid oxygen and hydrogen tanks, fuel leaks, storms and other difficulties, but we at **All About Space** cannot wait for the launch of Artemis I – the mission that will land humankind on the surface of the Moon again. The launch is now slated for October, so this month we thought it was fitting to provide a complete overview to our natural satellite. From the missions that explored the surface to its fascinating features, we hope that you'll be inspired to look up with your telescope, binoculars or even naked eye to explore the craters, lunar seas and mountains that pepper its chalky surface.

It isn't just about the Moon this month, though. We also have some top tips on how you can flawlessly be an even better astronomer, get up close to the biggest stars in the universe, catch up with Astronomer Royal Lord Martin Rees and plenty more.

I'll leave you to get excited for the launch of Artemis! Don't forget to check out our sister site **space.com** for the latest happenings around the Solar System, the wider universe and in the world of spaceflight.

I'll see you next time!

GEMMA LAVENDER
Content Director

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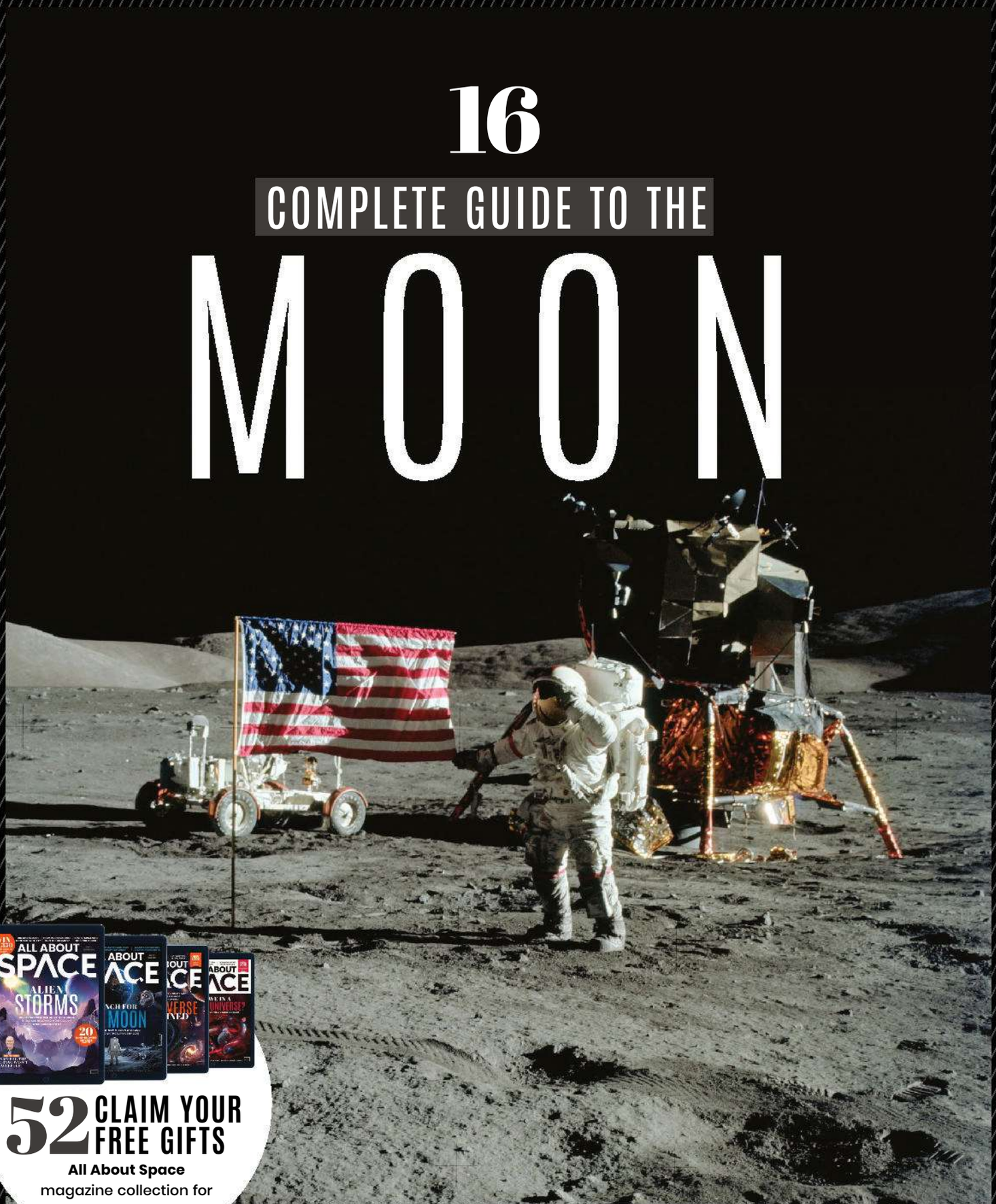

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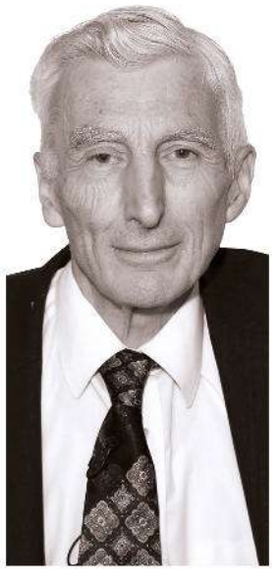

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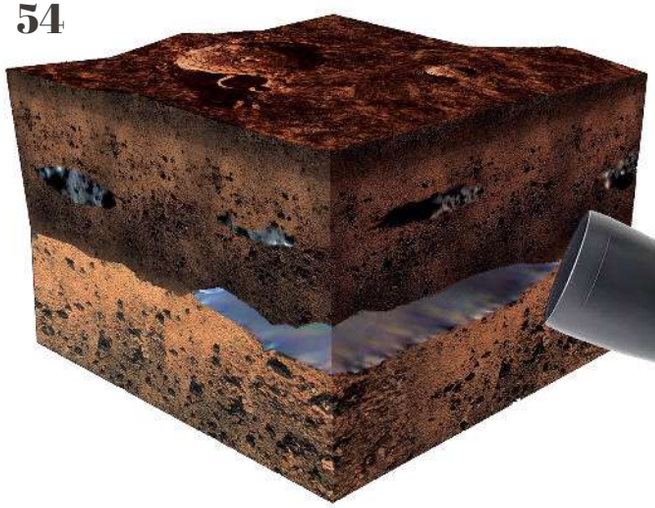

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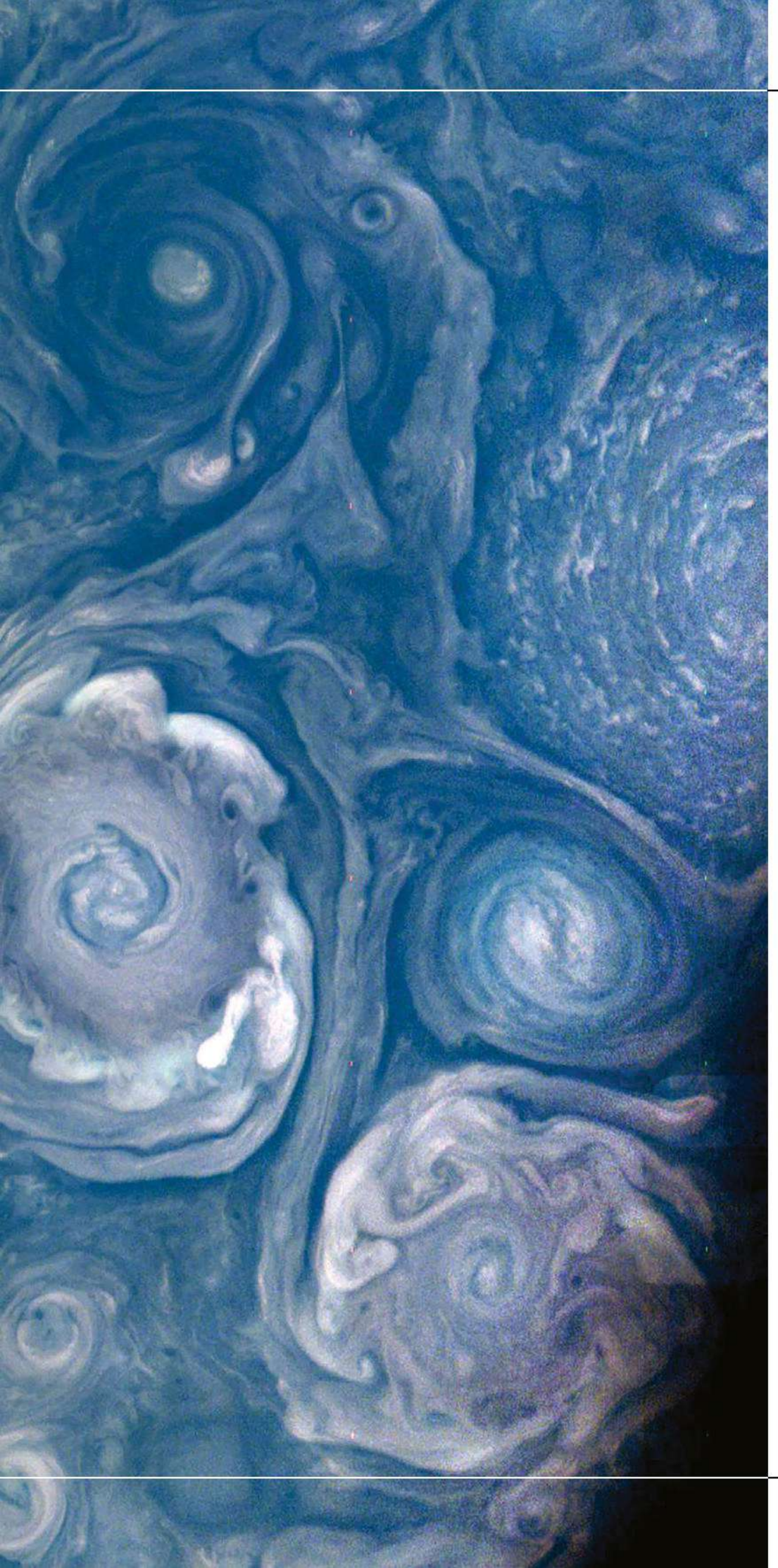
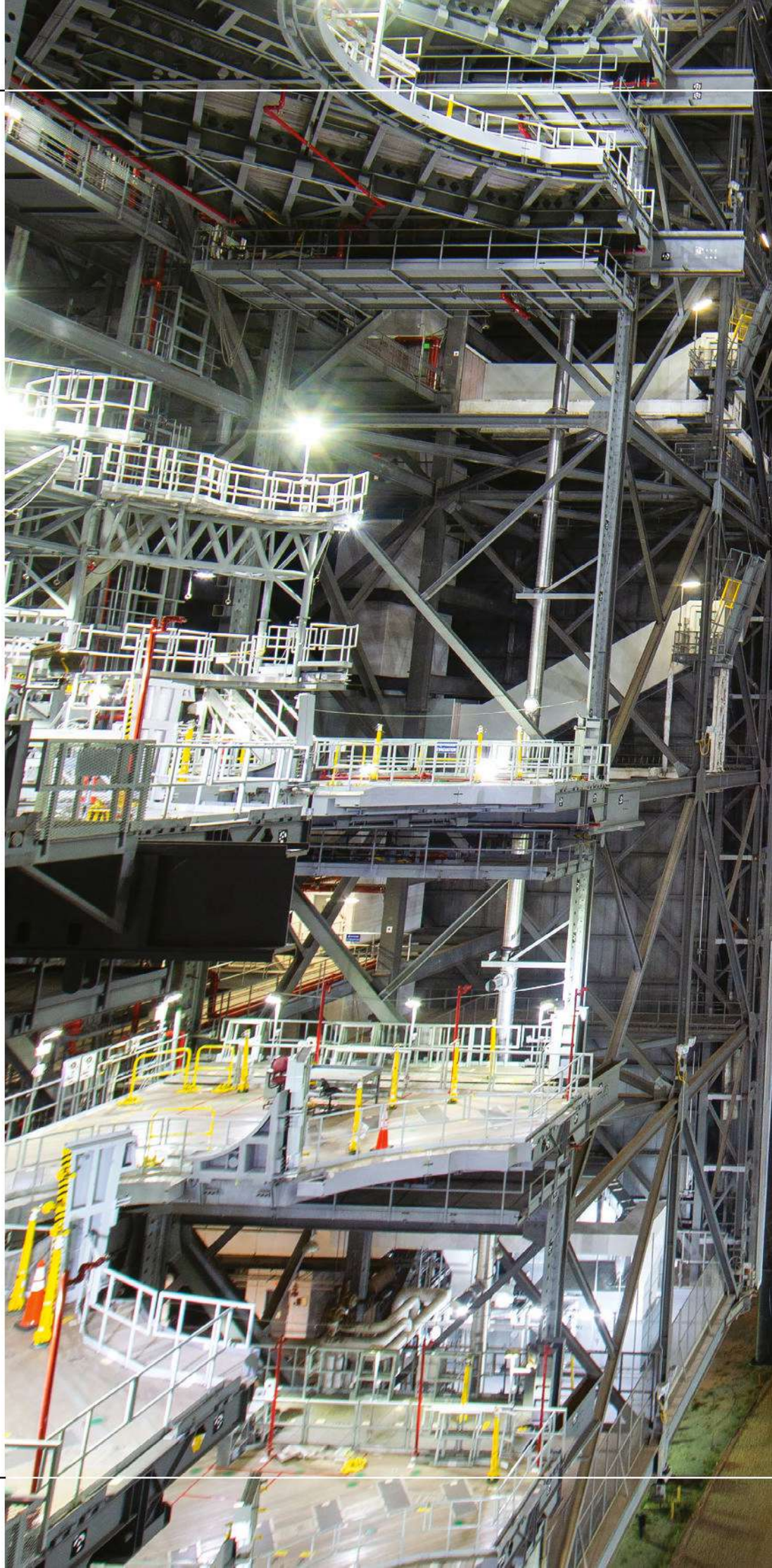


27 July 2022

Juno sees hurricanes at Jupiter's north pole

NASA's Juno probe snapped these mesmerising images of powerful storms around the north pole of Jupiter during its close approach to the planet on 5 July. The storms are over 50 kilometres (30 miles) deep and hundreds of kilometres wide. Scientists are still trying to understand what drives the formation of these storms in Jupiter's atmosphere and gives them their striking colours. Observations have revealed that these cyclones have different colours based on the direction of their spin and their location. This image is the result of NASA asking space enthusiasts and citizen scientists to help categorise these storms and other atmospheric phenomena captured by Juno as part of the Jovian Vortex Hunter project. Brian Swift created this image using raw JunoCam image data.

© NASA/JPL-Caltech



19 August 2022

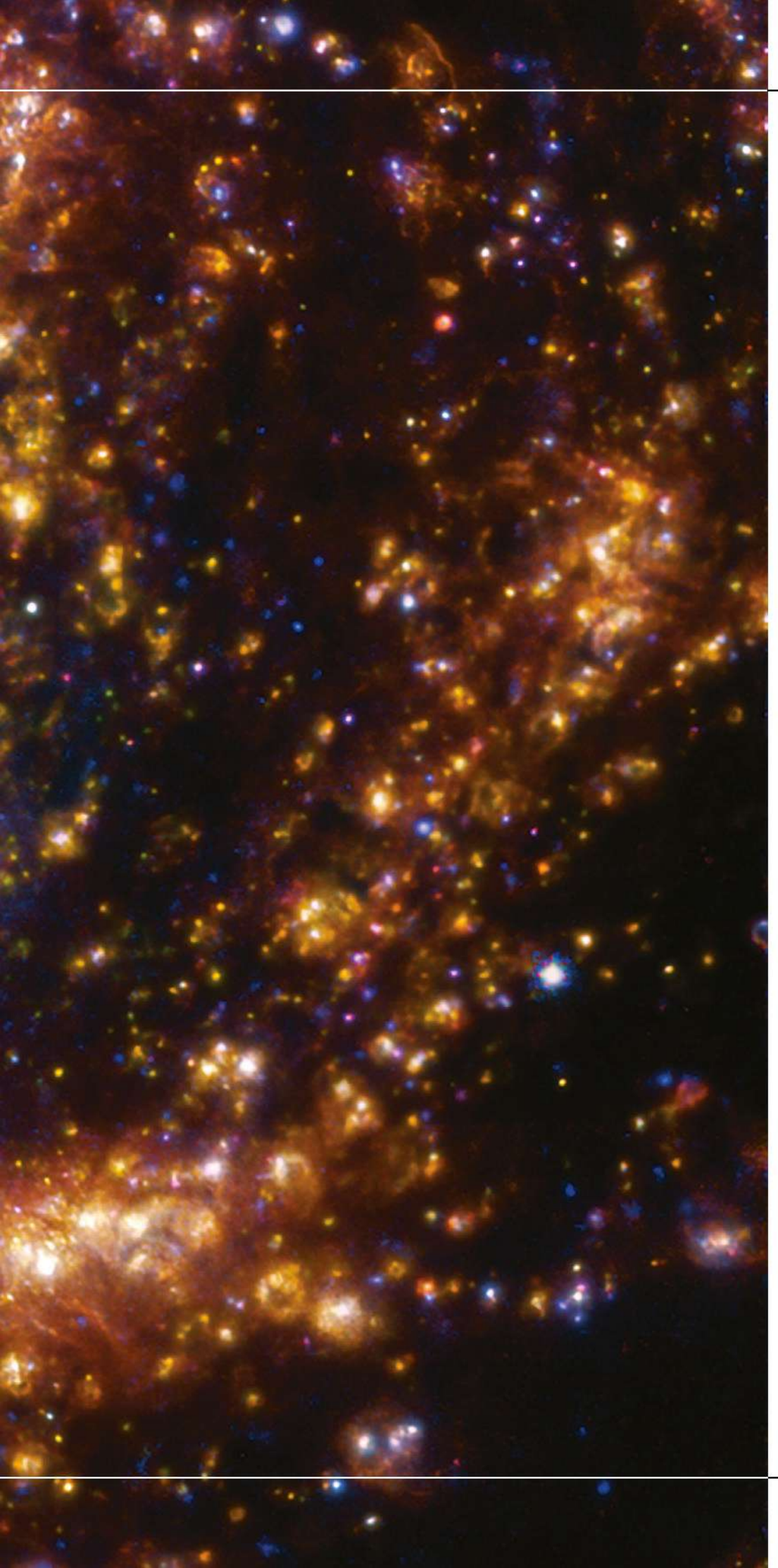
Artemis gets ready to roll

NASA's Artemis I Moon rocket headed to the launchpad on 19 August, taking a step closer to a landmark lunar mission. Artemis I is an uncrewed test flight of the huge Space Launch System (SLS) megarocket and its Orion spacecraft, and it began the rollout to a Kennedy Space Center (KSC) launchpad at 02:00 GMT on 17 August. The Orion, stacked atop the rocket, began moving from the KSC's Vehicle Assembly Building (VAB) for a journey that took more than ten hours. The crawler carrying the hardware had to make a journey to Launch Complex 39B at roughly 1.6 to 3.2 kilometres (one to two miles) per hour.

NASA elected to bring the rocket out a full two days earlier than planned. The agency revealed that the team finished flight termination system testing, the last major activity required until the rocket was closed out and the final access platforms at the VAB were retracted. At the time of writing, NASA hasn't released a detailed schedule of the rollout, expected to last between 8 and 11 hours depending on weather conditions, road conditions and other technical matters.

© NASA

ARTEMIS



1 August 2022

Whirlpool of gold

An enthralling new photo captures bright, golden swirling clouds of gas that generate an exceptionally high rate of star formation. This stellar nursery, a spiral galaxy known as NGC 4303, or Messier 61, is located 50 million light years from Earth in the constellation of Virgo. NGC 4303 is one of the largest galactic members of the Virgo Cluster – a large nearby grouping of galaxies.

NGC 4303 is considered a starburst galaxy, where an unusually high amount of stars are being born. Studying this type of galaxy helps astronomers better understand star formation across the universe. "Stars form when clouds of cold gas collapse," European Southern Observatory (ESO) officials said. "The energetic radiation from newly born stars will heat and ionise the surrounding remaining gas." The photo, taken using the ESO's Very Large Telescope (VLT) in Chile, shows bright swirling clouds of the ionised gas, appearing as a whirlpool of gold. The swirling clouds are like cosmic breadcrumbs, tracing the path of new stars being born.

© ESO

Fuel leak delays NASA's Artemis I Moon mission launch

Reported by Tariq Malik

NASA called off the second attempt to launch an ambitious test flight of its new Moon rocket on 3 September, this time because of a stubborn leak that delayed fuelling. The space agency hoped to launch its Artemis I Moon mission atop a towering Space Launch System (SLS) megarocket at 18:17 GMT, but a hydrogen fuel leak detected about seven hours before liftoff thwarted the attempt. "We have a scrub for the day, a cutoff of the launch attempt for Artemis I," NASA commentator Derrol Nail said during a live broadcast.

NASA engineers repeatedly tried to staunch the fuel leak during the Artemis I countdown. First they tried to warm the tank connector and chill it with cold fuel to reseat the hydrogen quick-disconnect connector. Next engineers tried to repressurise it with helium, then returning to the warm-and-chill method to stop the leak. But all three attempts failed. The delay means the agency will have to wait to make its next launch attempt. And that's if the source of the leak can be fixed in time. "We'll go when it's ready. We don't go until then, and especially now on a test flight," NASA administrator Bill Nelson said in televised comments after the scrub. "This is part of the space business."

Astronaut Victor Glover said the decision to scrub was "absolutely the right call". "This is not a letdown," Glover said after the scrub. "This is understanding how these things work, these really incredibly complex machines that we want to try to integrate human beings in."

If NASA has to roll Artemis 1's SLS rocket back inside its Vehicle Assembly Building hangar for repairs, the launch will slip to October, Nelson said. NASA already plans to launch four astronauts to the International Space Station on SpaceX's Crew-5 Dragon mission in early October, so an Artemis 1 launch that month would be later in the month. Artemis 1 does have a launch window in mid-September, but NASA would likely have to push to mid-October due to the time needed to roll back and forth between Pad 39B and the Vehicle Assembly Building. That October window opens on 17 October and closes on 31 October, with cutouts between 24 and 26 October and on 28 October.

SETI pioneer Frank Drake, of Drake equation fame, passes away at 92

Reported by Mike Wall

Astronomer Frank Drake, who pioneered the modern search for intelligent life in the universe, passed away on 2 September at the age of 92. Drake is best known for the equation that bears his name, a formula that estimates how many detectable alien societies may exist within our Milky Way. Drake devised his famous equation in 1961, a year after he initiated Project Ozma at Green Bank Observatory, which used a radio telescope to hunt for possible signals from extraterrestrial civilisations.

"His strategy is still enthusiastically deployed six decades after his pioneering SETI experiment. This is a truly remarkable circumstance, and nearly unprecedented in exploration," radio astronomer Seth Shostak wrote in a 2020 tribute to Drake, for many years a colleague of his at the SETI Institute in Mountain View, California. In that tribute, Shostak stressed how tough it was for Drake to blaze his trail. Drake had to battle through the giggle factor, which discouraged pretty much every other scientist from even voicing an interest in SETI. "It was a taboo subject in astronomy," Drake told Shostak. "Nobody else was doing a search, because they were all afraid. I was too dumb to be afraid." The giggle factor has been melting away recently, thanks in part to Drake and the people he inspired, several generations of astronomers whose ranks include Seth Shostak and Jill Tarter. Scientific discoveries have also helped pull SETI off the fringes and into the mainstream, chief among them the finds of the ongoing exoplanet revolution.

Drake was born on 28 May 1930 in Chicago. He earned a bachelor's degree in engineering physics from Cornell University and a master's and a doctorate in astronomy from Harvard. Drake was an astronomy professor at Cornell from 1964 to 1984, then held a similar post at the University of California, Santa Cruz (UCSC) from 1984 to 1996. He stayed on as an emeritus professor at UCSC after that. Drake also directed the SETI Institute's Carl Sagan Center for the Study of Life in the Universe and chaired the institute's board of trustees. Among many other distinctions and responsibilities, he was a member of the US National Academies of Sciences, Engineering and Medicine, and he also chaired the US National Research Council's Board of Physics and Astronomy from 1989 to 1992.

NASA awards SpaceX $1.4 billion for five more astronaut missions

Reported by Elizabeth Howell

NASA has tasked SpaceX with carrying out five additional astronaut missions to the International Space Station (ISS) under a new $1.4 billion deal, which modifies an existing agreement between the two organisations. The deal, which will employ SpaceX's Crew Dragon spacecraft and Falcon 9 rockets, "allows NASA to maintain an uninterrupted US capability for human access to the space station until 2030," NASA officials said. The pact will cover missions Crew-10 through Crew-14, representing around 20 seats overall.

While NASA is banking on Boeing's Starliner capsule flying people to space relatively soon, for now SpaceX is the only company certified to fly operational crewed missions for the agency. SpaceX also received a trio of astronaut flights from NASA in December as part of a sole-source modification to its Commercial Crew Transportation Capabilities contract, first awarded in 2014. "SpaceX's crew transportation system is the only one certified to meet NASA's safety requirements to transport crew to the space station and to maintain the agency's obligation to its international partners in the needed time frame," agency officials said at the time. SpaceX's deal is now worth a total of $4.9 billion.

NASA plans on running astronaut missions to the ISS until at least 2030; the agency was just approved by President Joe Biden to extend its participation in the orbiting complex by six more years, past 2024. Major space station partner Russia, however, intends to withdraw from the ISS after 2024 to build a Russian-operated space station. That new station likely won't be ready until at least 2028. There is no word yet on how NASA and any remaining ISS partners would fill in operational gaps left by the Russians, like boosting the space station periodically to keep it at the proper altitude above Earth.

SpaceX suits are sleek, grey and white

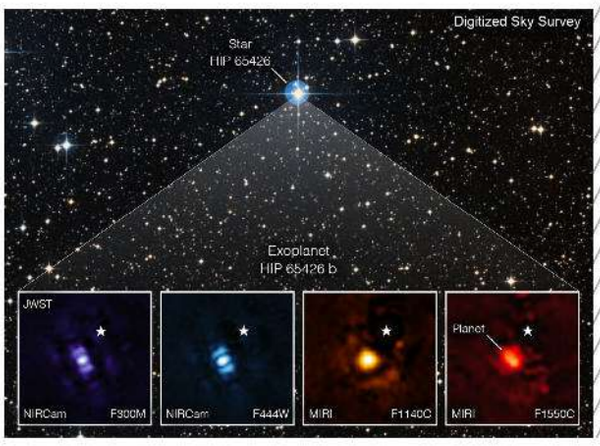
The James Webb Space Telescope snags its first direct photo of an alien world

Reported by Tereza Pultarova

Webb took its first direct image of a planet orbiting a distant star, proving its potential to revolutionise exoplanet research. The majority of exoplanets have only been observed through temporary dips in brightness of the stars they orbit. Only about 24 have been imaged directly, but that might soon change. Less than two months after it started science operations, Webb has delivered its first direct photo of a planet beyond our Solar System. A gas giant orbiting the star HIP 65426, some 385 light years from Earth, appears in the image as a tiny splotch close to the glowing star. Webb photographed the exoplanet using its Near-Infrared Camera (NIRCam) and Mid-Infrared Instrument (MIRI), each of which focuses on a different flavour of infrared light. Scientists discovered the planet in 2017 with the Very Large Telescope in Chile. Webb isn't tailored to discovering exoplanets and will instead excel at teaching scientists about worlds other observatories identified.

Exoplanets are extremely difficult to observe directly because they are so much fainter than the stars they orbit. This one, HIP 65426 b, could only be spotted thanks to a combination of factors. First, it's extremely far away from its parent star at 100 times the distance from the Sun to Earth – for comparison, Pluto orbits only 40 Sun-Earth distances from the Sun. Second, HIP 65426 b is also extremely massive – 12 times the size of Jupiter, the Solar System's largest planet.

Still, HIP 65426 b is about 10,000 times fainter than its host star in the near-infrared and a few thousand times fainter in the mid-infrared part of the spectrum. Because of its sensitivity, however, Webb was capable of separating the two objects.



Webb was able to separate the star and planet

© NASA; Getty images

WIN

CELESTRON ASTROMASTER 102AZ WORTH OVER £250

Kick-start a hobby in astronomy with this beginner's telescope

A dual-purpose telescope that's ideal for both terrestrial and celestial viewing, the Celestron AstroMaster 102AZ produces bright, crisp and clear images of the lunar surface as well as the planets. Spotting the moons of Jupiter, the rings of Saturn and touring the craters and lunar mare on the Moon has never been easier. Quick and easy no-tool assembly means that you spend less time assembling the AstroMaster 102AZ and more time observing the wonders of the night sky. The rugged preassembled tripod with steel tube legs provides a rigid and stable platform which allows for steady views. An alt-azimuth control with clutch ensures smooth and accurate pointing, while two eyepieces and TheSkyX – First Light Edition astronomy software with a 10,000-object database provides everything you need to get started in stargazing.

To be in with a chance of winning, answer this question:

Which of the following is not a sea, or mare, on the Moon?

A: Copernicus

B: Vaporum

C: Fecunditatis

Competition ends on 3 November 2022

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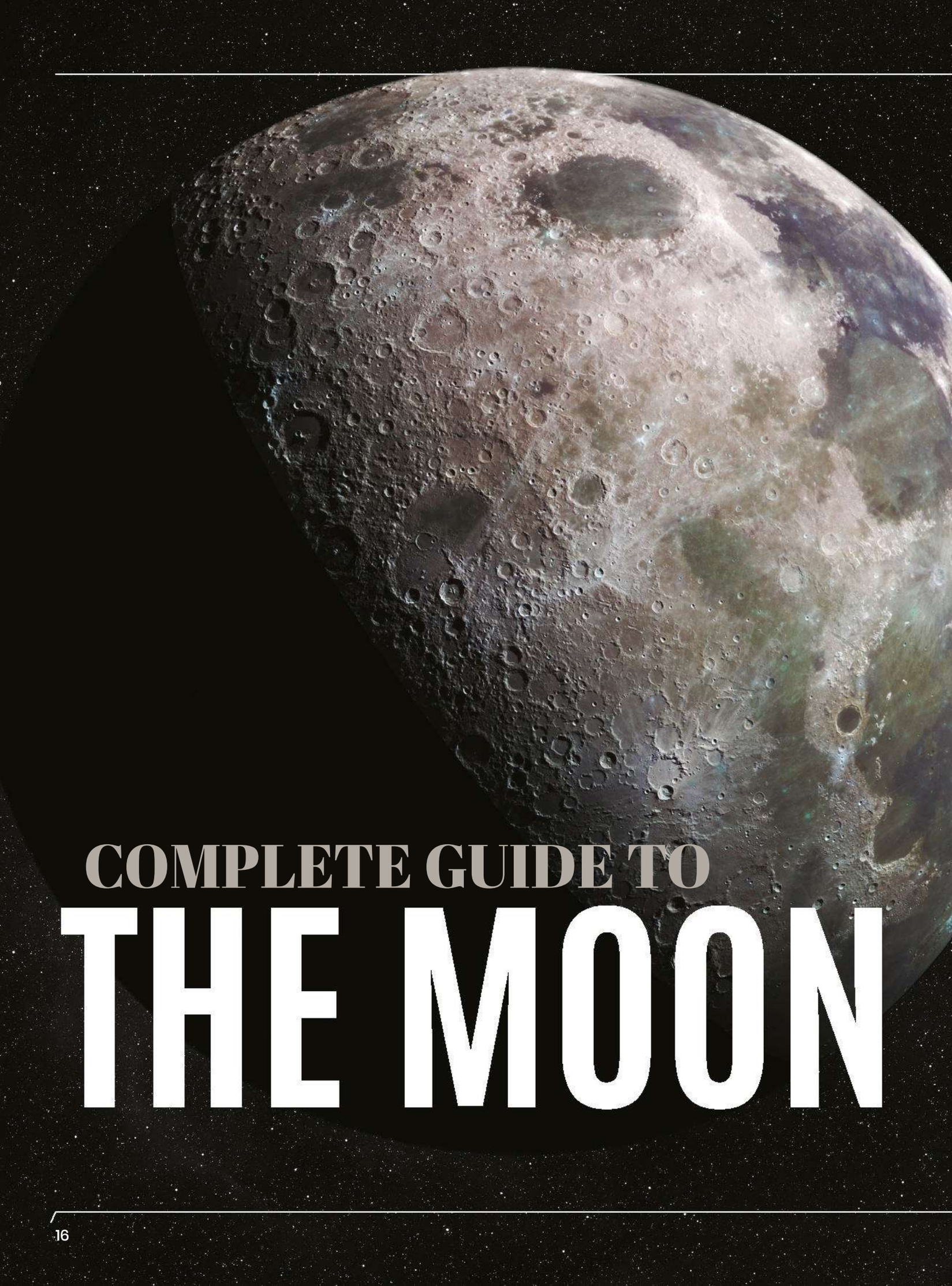


COMPLETE GUIDE TO THE MOON

Even though we know more about our natural satellite than any other celestial body – and have even visited it – the Moon continues to fascinate us

Written by Shanna Freeman

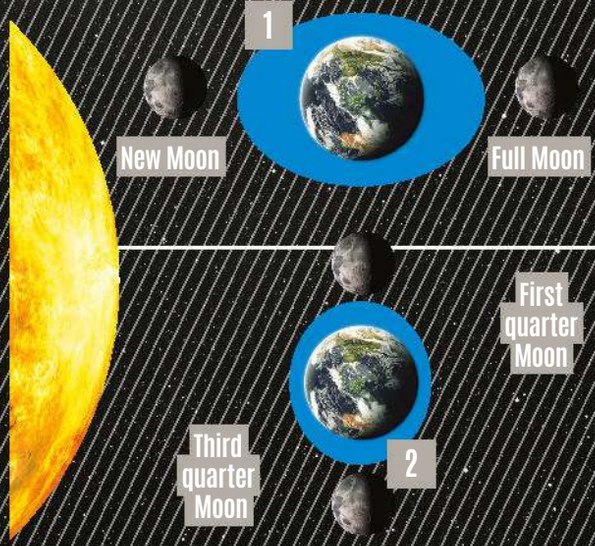
Because we can easily discern features on the Moon with the naked eye, it's been a source of wonder to us since ancient times. The Moon is the brightest object in our sky after the Sun, and influences everything from our oceans to our calendars. It's always been 'the Moon' because we didn't know that there were any others. Once Galileo discovered in 1610 that Jupiter had satellites, we've used the word 'moon' to describe celestial bodies that orbit larger bodies, which orbit stars. Since the Moon has always been so present it might not seem worth studying, yet there's a reason why we continue to return to it – we still have plenty to learn from our satellite.

"The Moon is the fifth-largest and second-densest satellite in the Solar System"

The Moon is the fifth-largest and second-densest satellite in the Solar System. Its diameter is 27 per cent of Earth's at 3,476 kilometres (2,160 miles), while its mean density is 60 per cent that of Earth's. This makes the Moon the largest satellite in size relative to the planet that it orbits. The Moon is also unusual because its orbit is more closely aligned to the plane of the ecliptic

THE MOON AND TIDES

Along with the Sun, the Moon exerts serious force on Earth's tides. Whether the tides vary widely or not much at all has a lot to do with the interactions between the solar and lunar cycles. When they are together, their combined effects produce tidal variations called spring tides – high tides are very high and low tides are very low. If the Sun and Moon are on the opposite sides of the sky, they nullify each others' effects, producing neap tides – with little variation.



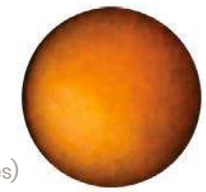
1 Spring tide
During new and full Moon, both the Sun and Moon exert a strong effect, producing spring tides.

2 Neap tide
In first and third quarter Moon, the Sun and Moon have little effect on tidal range, leading to neap tides.

©Getty: NASA

MEASURING UP THE MOON BY ITS DIAMETER

Ganymede
Jupiter
5,268 kilometres (3,300 miles)



Titan
Saturn
5,150 kilometres (3,200 miles)

Callisto
Jupiter
4,821 kilometres (3,000 miles)

Io
Jupiter
3,642 kilometres (2,300 miles)

The Moon
Earth
3,476 kilometres (2,160 miles)

Europa
Jupiter
3,122 kilometres (1,940 miles)

Triton
Neptune
2,700 kilometres (1,700 miles)

Titania
Uranus
1,578 kilometres (980 miles)

the plane in which Earth orbits. Most planetary satellites orbit closer to their planet's equatorial plane, but the Moon is inclined from the plane of the ecliptic by approximately 5.1 degrees.

Its average distance from Earth is 384,400 kilometres (239,000 miles), and it completes an orbit once every 27.3 days. The Moon is in synchronous rotation with Earth – its rotation and orbital period are the same – so the same side is almost always facing our planet. This is called the 'near side' of the Moon, while the opposite side is the 'far' or 'dark' side, although it gets illuminated just as often as the near side. This hasn't always been the case: the Moon used to rotate faster but the influence of Earth caused it to slow and become locked.

Although we say that we can only see one side of the Moon at a time, that's not strictly true. The Moon's orbit isn't quite circular – it has an eccentricity of 0.0549. The Moon also wobbles a bit along its orbit. These two factors cause some variations in how much of the Moon that we see, called librations. When the Moon is closest to Earth, called the perigee, it orbits slightly slower than it rotates. This means that we can actually get a glimpse of about eight degrees of longitude of its eastern far side. When the Moon is at its furthest point away in its orbit, the apogee, its orbit is slightly faster than its rotation. So we get a glimpse of eight degrees of longitude on its western far side. This is called longitudinal libration.

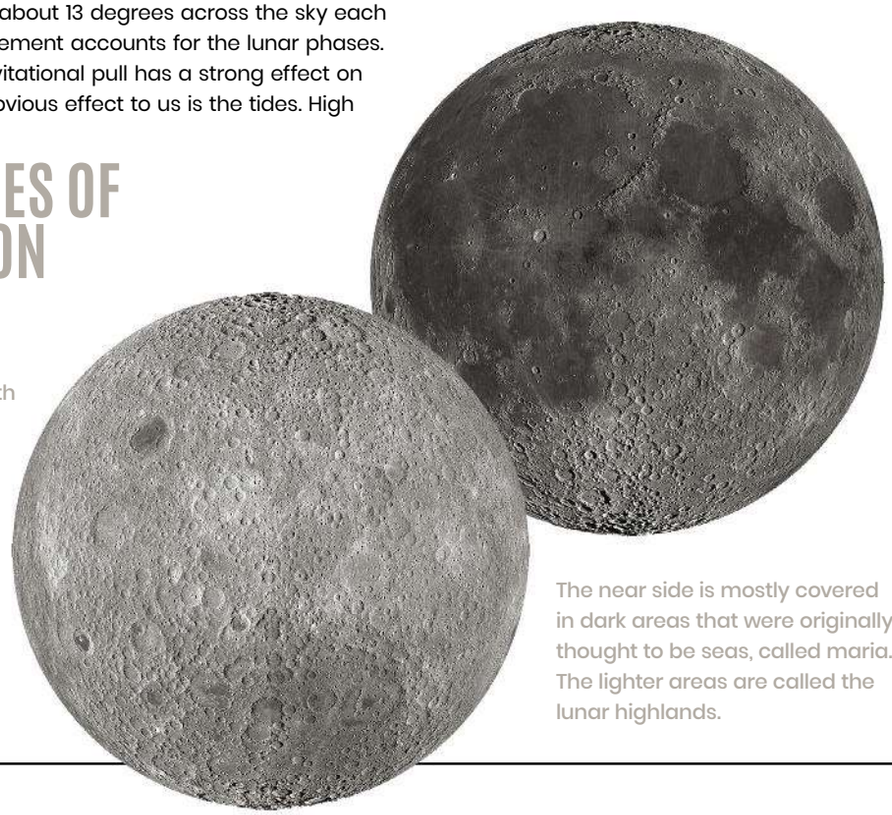
The Moon also appears to rotate towards and away from Earth. This is due to the 5.1-degree inclination of its orbit, as well as the 1.5-degree tilt of the Moon's equator to the plane of the ecliptic. This results in us seeing about 6.5 degrees of latitude on the far side along both the sides of the poles. The Moon's orbit also means that it appears to move about 13 degrees across the sky each day, and this movement accounts for the lunar phases.

The Moon's gravitational pull has a strong effect on Earth. The most obvious effect to us is the tides. High tide occurs when the level of water at the coastline rises, and low tide occurs when the water rushes further out. While some coastlines experience one high tide and one low tide per day, of equal strength, others have different strengths, timing and numbers of tides. Measuring and predicting these tides is vital for everything from fishing to navigating intercoastal waterways. We use the term 'tides' to describe oceanic tides, but tides also occur on a smaller level in lakes as well as Earth's atmosphere and crust.

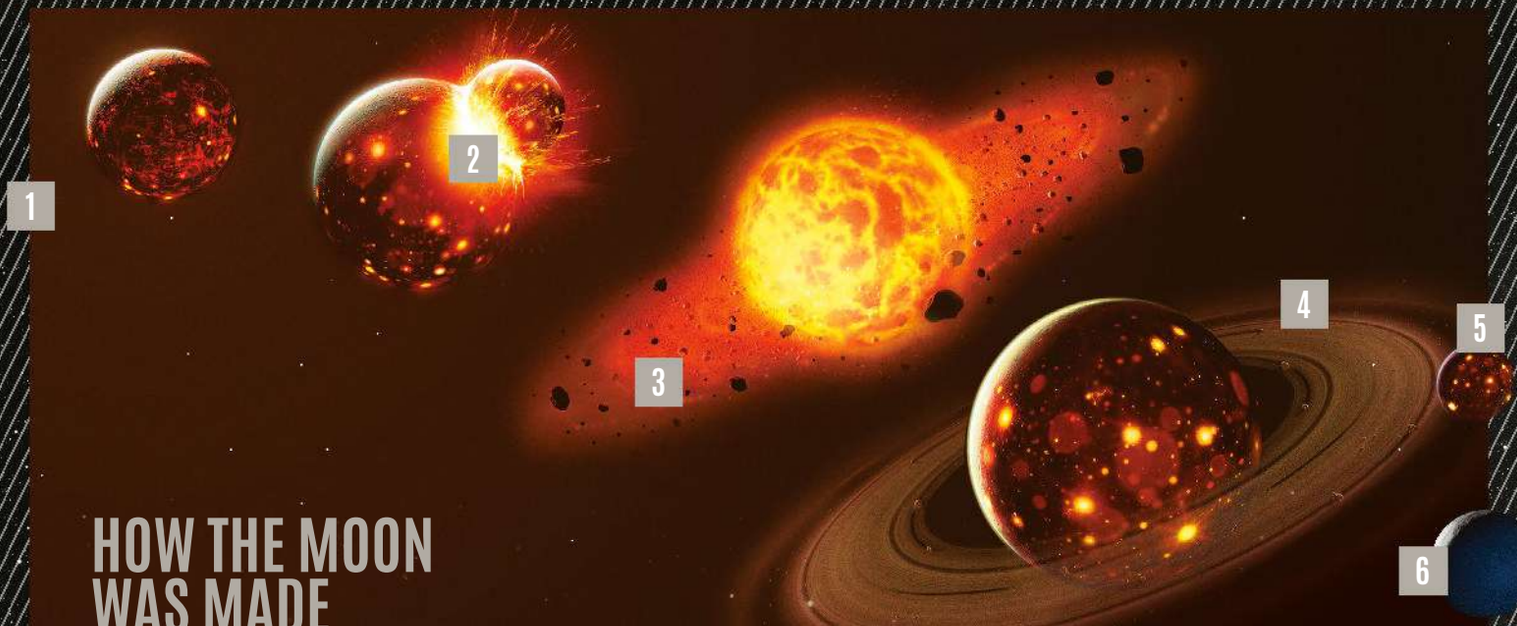
Scientists believe that the Moon formed when a huge celestial body about the size of Mars – which has been given the name Theia – impacted with a young Earth. This is known as the giant impact hypothesis. This force sent debris out into Earth's orbit, which fused to form the Moon. However, in 2012 an analysis of rock samples taken from the Moon during the Apollo missions showed that the Moon's composition is almost identical to Earth's. This calls the giant impact hypothesis into question because previously we thought that at least some of the Moon's material had to have come from Theia.

TWO SIDES OF THE MOON

As opposed to the near side, the far side is covered with craters and very little maria. This may be because it's hotter on that side, or because it experienced a collision.



The near side is mostly covered in dark areas that were originally thought to be seas, called maria. The lighter areas are called the lunar highlands.



HOW THE MOON WAS MADE

1 Theia nears Earth
A Mars-sized object on an unalterable collision course with early Earth.

2 Earth is hit
The impactor hit Earth in a head-on collision, vaporising both Theia and the mantle of Earth.

3 Material is thrown out
The vaporised material from both bodies mixed and was thrown outwards.

4 Debris gathers
Smaller objects began to condense out of the vapour while continuing to orbit around Earth.

5 The Moon takes shape
Many of the smaller objects stuck together to form a protomoon in orbit around Earth.

6 Our companion is formed
Eventually all the pieces came together to form the basis of the Moon we see today.

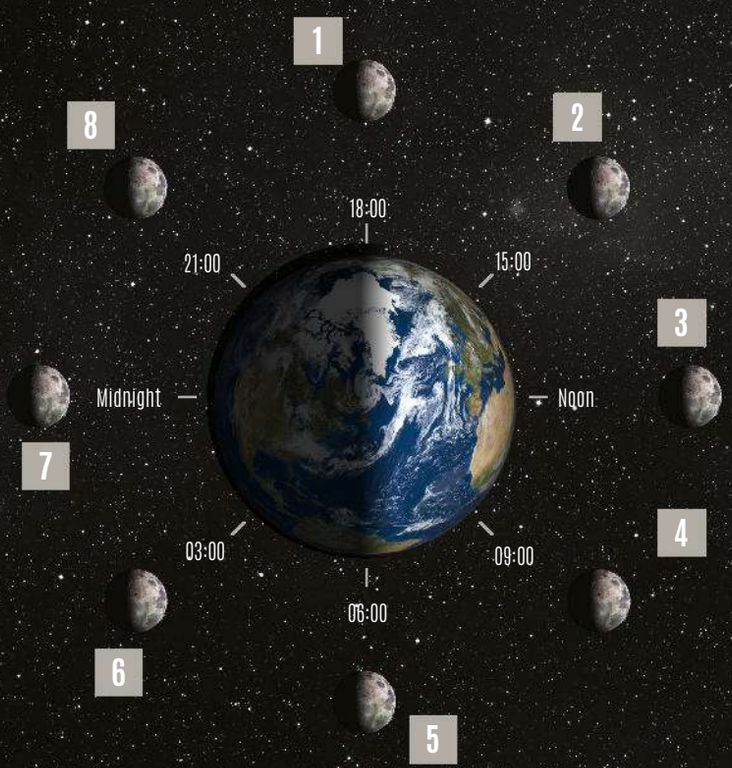
THE MOON'S ORBIT

1 First quarter
Half of the Moon is visible in the afternoon and early evening.

2 Waxing crescent
Up to 49 per cent of the Moon is visible in the afternoon and after dusk.

3 New Moon
The first visible crescent in the southern hemisphere, seen after sunset.

4 Waning crescent
Up to 49 per cent is visible just before dawn and in the morning.



5 Third quarter
Half of the Moon is visible in the late evening and morning.

6 Waning gibbous
Between 51 and 99 per cent of the Moon is visible for most of the evening and in the early morning.

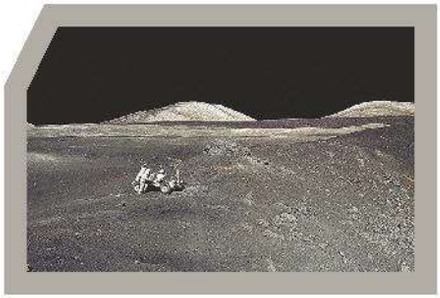
7 Full Moon
The entire Moon is visible all night long.

8 Waxing gibbous
Between 51 and 99 per cent is visible in the later afternoon and most of the evening.

© Getty/NASA

INSIDE AND OUT

Earth's natural satellite shares some remarkable similarities with our home planet

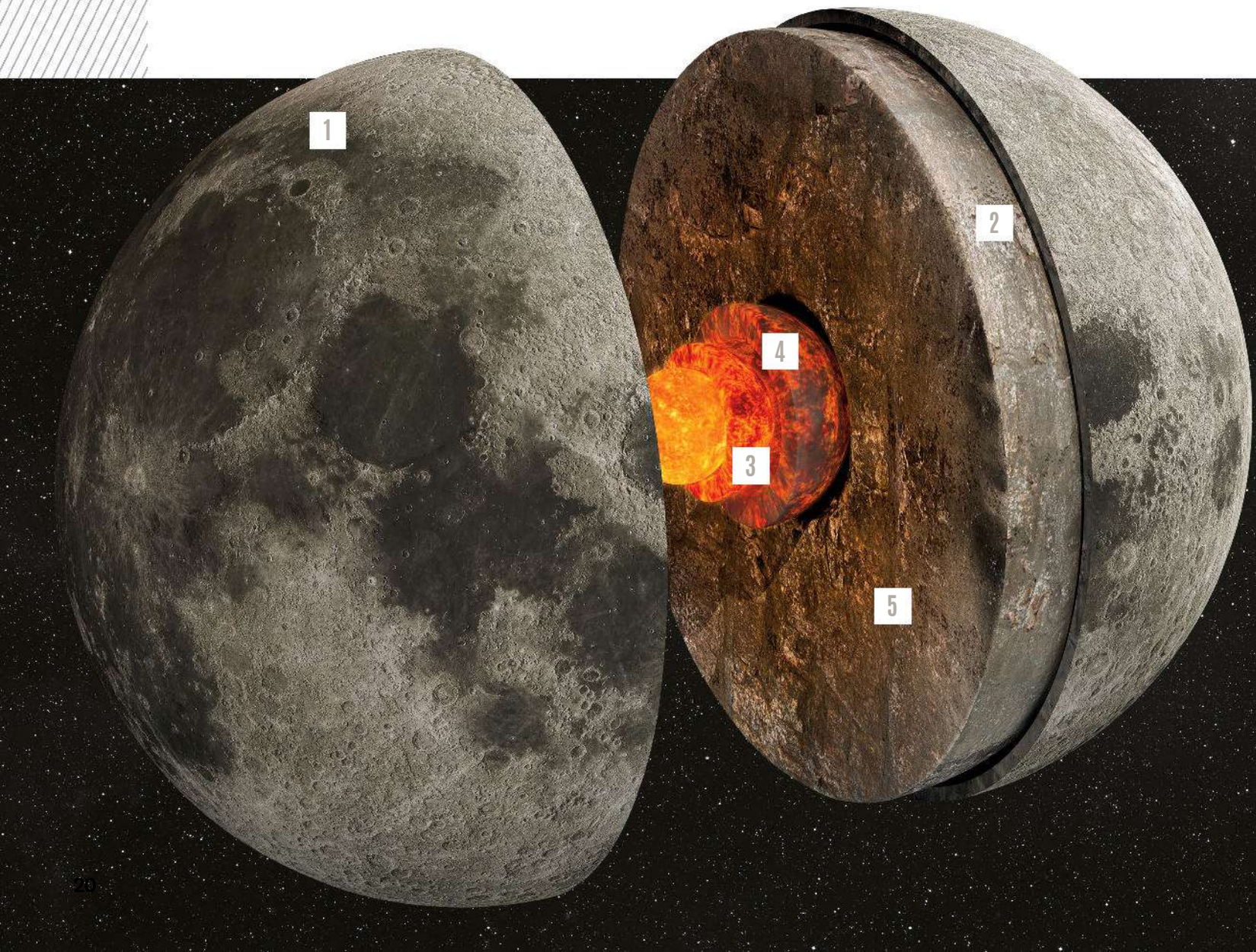


A When astronauts explored the Moon they discovered it has moonquakes

Although the Moon may seem like a solid rock, it's actually differentiated like Earth; it has a core, a mantle and a crust. The Moon's structure likely came from the fractional crystallisation of a magma ocean that once covered it. This probably happened not long after the Moon was formed, about 4.5 billion years ago. As the magma ocean cooled, its composition changed as the different minerals within the melt crystallised into solids. The denser materials sank, forming the mantle, while less dense materials floated on top and formed the crust.

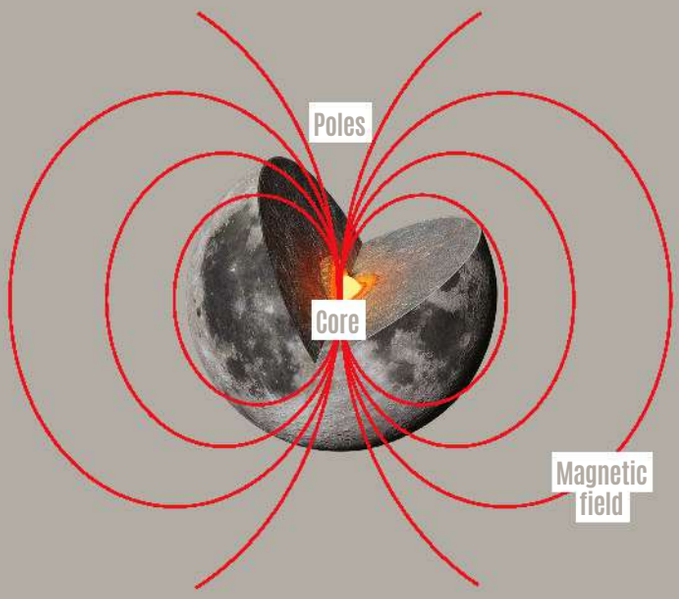
The core is probably very small, with a radius about 20 per cent the total size of the Moon. By contrast, most differentiated celestial bodies have cores about 50 per cent of their total size. The core itself comprises a solid innermost core that is rich in iron as well as nickel and sulphur, with a radius of 240 kilometres (150 miles). This is surrounded by a fluid outer core with about a 300-kilometre (186-mile) radius. Between the core and the mantle, there's a boundary layer of partially melted iron that has about a 500-kilometre (300-mile) radius. It is also known as the lower mantle. The upper mantle is mafic – rich in magnesium and iron, topped by a crust of igneous rock called anorthosite. It mainly includes aluminium, calcium iron, magnesium and oxygen, with traces of other minerals. We estimate the crust is around 50 kilometres (31 miles) thick.

The Moon has no plate tectonics, but it does have seismic activity. When astronauts visited the Moon they discovered that there are moonquakes – the Moon's equivalent of earthquakes. Moonquakes aren't nearly



THE MAGNETIC FIELD MYSTERY

The Moon has an external magnetic field – it's less than one-hundredth that of Earth's magnetic field. It's not a dipolar magnetic field like Earth, which has a field that radiates from the north and south poles. Researchers believe the Moon once had a dipole magnetic field, created by a dynamo – a convecting liquid core of molten metal. But we aren't sure what powered that dynamo. It could have worked like Earth's dynamo. Earth's dynamo powers itself as elemental radioactive decay maintains convection in the core. The Moon could also have had a dynamo powered by the cooling of elements at the core.



1 Crust
The crust is igneous rock called anorthosite, about 50 kilometres (31 miles) thick.

2 Mantle
The main mantle is mafic – rich in magnesium and iron.

3 Inner core
The inner core is rich in iron with a radius of 240 kilometres (150 miles), and much smaller than the cores of most terrestrial bodies.

4 Outer core
The fluid outer core has a 300-kilometre (186-mile) radius.

5 Partial melt
This partially melted layer is mostly iron, with a radius of 500 kilometres (300 miles).

as strong as earthquakes, but they can last longer because there's no water to lessen the effects of the vibrations. Seismometers showed that the strongest moonquakes are about 5.5 on the Richter scale. There are four different types of moonquakes: shallow, deep, thermal and meteorite. Shallow ones occur 20 kilometres (12 miles) below the surface, while deep moonquakes can be as deep as 700 kilometres (435 miles). These deep moonquakes are probably related to stresses on the Moon caused by its eccentric orbit and gravitational interactions between it and Earth. Thermal earthquakes occur when the crust of the Moon heats and expands. Shallow moonquakes are the strongest and most common. Nearly 30 were recorded between 1972 and 1977 by seismometers on the surface. This seismic data has helped us to determine the Moon's internal composition.

The dominating feature on the near side of the Moon's surface, called maria, are the result of ancient volcanic activity. These vast, dark plains are basalts – igneous rock that formed after lava erupted due to partial melting within the mantle. These basalts show that the Moon's mantle is much higher in iron than Earth's, and has a varied composition. Some basalts are very high in titanium, while others are higher in minerals like olivine.

These basalt maria have influenced the Moon's gravitational field because they're so rich in iron. The gravitational field contains mascons, positive gravitational anomalies that influence how spacecraft orbit the Moon. The maria can't explain all of the mascons that have been tracked by the Doppler effect on the radio signals emitted by spacecraft that orbit the Moon. And there are also some large maria without associated mascons.

THE MOON BY NUMBERS

400
How many times bigger the Sun is than the Moon. It's also about 400 times further away from Earth, which is why they look the same size in the sky

29.5 DAYS
The length of a lunar month, longer than the amount of time it takes the Moon to orbit Earth because Earth is moving, too

12
The number of people who have set foot on the Moon

3.8 CENTIMETRES
The distance the Moon moves away from Earth each year

13 HOURS
The amount of time it takes to reach the Moon by rocket

16.6 KILOGRAMS
The amount you would weigh on the Moon if you weighed 100 kilograms on Earth

©Getty: NASA

ON THE SURFACE

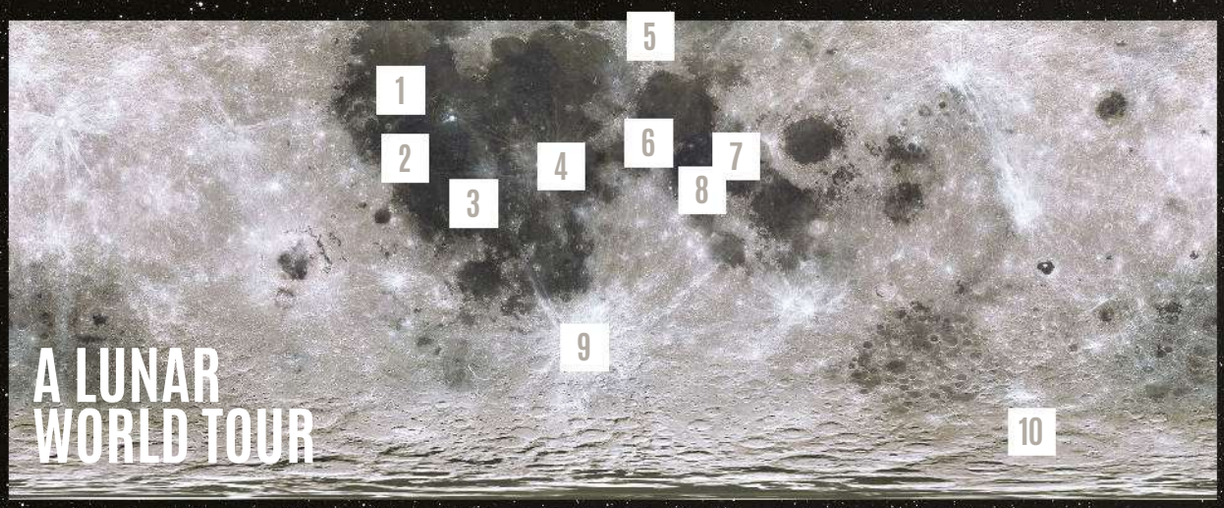
The surface of the Moon is about contrasts: light and dark, hot and cold

The landscape of the Moon is dominated by three main features: maria, terrae and craters. The basalt maria appear dark due to their high iron content and are much more prevalent on the near side of the Moon. Other volcanic features on the surface include domes and rilles. Domes are shield volcanoes that are round and wide with gentle slopes, while rilles are twisting sinuous formations caused by channels of flowing lava.

The lighter areas on the Moon are called terrae, or lunar highlands. They are made up of anorthosite, the type of igneous rock that dominates the overall crust of the Moon. While this type of rock can be located in some places on Earth, it's not generally found on the surface due to plate tectonics and deposits. These highlands reflect light from the Sun and make it appear that the Moon is glowing at night.

Both the maria and terrae have impact craters which were formed when asteroids and comets struck the surface of the Moon. These craters range in size from very tiny to massive. It is estimated that there are

The last manned mission to the Moon took place in December 1972



A LUNAR WORLD TOUR

1 Oceanus Procellarum
This mare is so large that it was deemed an ocean, covering about 4,000,000 square kilometres (1,500,000 square miles).

2 Luna 9
This site marks the first soft landing of an unmanned spacecraft on the Moon, launched by the Soviet space program on 31 January 1966.

3 Surveyor 1
The first American soft Moon landing happened here, launched on 30 May 1966.

4 Copernicus
This crater is well known because it can be easily seen from Earth. It is a younger crater, about 800 million years old, with a prominent system of ejecta rays.

5 Vallis Alpes
This lunar valley bisects a mountain range called the Montes Alpes, and extends 166 kilometres (103 miles).

6 Montes Apenninus
This mountain range is about 600 kilometres (370 miles) long and has peaks up to 5 kilometres (three miles) high.

7 Mare Tranquillitatis
This mare was the landing site for the Apollo 11 spacecraft. It is slightly bluish because it has a high metal content.

8 Apollo 11
Neil Armstrong and Buzz Aldrin became the first men to set foot on the Moon, on 21 July 1969 as part of NASA's Apollo program.

9 Tycho
This distinctive crater has ejecta rays visible from Earth during a full Moon, reaching more than 1,000 kilometres (621 miles) from the crater.

10 Schrödinger
This huge crater near the south pole can only be viewed from orbit. It is 312 kilometres (194 miles) in diameter.

EXPLORING THE MOON: THE PAST

Apollo 11 21 July 1969
NASA astronauts Buzz Aldrin and Neil Armstrong became the first humans to set foot on another body in space when they landed on the Moon in 1969.

Apollo 12 19 November 1969
The second spacecraft to land on the Moon, Apollo 12, used a Doppler effect radar technique to land the spacecraft within walking distance of the Surveyor 3 probe, which had landed on the lunar surface about two years prior.

Apollo 14 5 February 1971
The commander on board the third spacecraft to land on the Moon was Alan Shepard who, a decade earlier on 5 May 1961, had become the second person in space after Yuri Gagarin and the first American as part of the Mercury program.

Apollo 15 30 July 1971
NASA deemed this Moon landing the most successful so far out of its manned missions. It is also known as the first of the longer missions to the Moon, called 'J missions', staying for three days.

Apollo 16 21 April 1972
Apollo 16 was the first spacecraft to land in the highlands on the Moon, which let the astronauts gather older lunar rocks.

Apollo 17 11 December 1972
This last manned mission to the Moon carried the Traverse Gravimeter Experiment, which measured relative gravity at different sites on the Moon.

Luna 1 4 January 1959
This Soviet probe was the first to reach the vicinity of the Moon and the first to break out of geocentric orbit. But it didn't impact the Moon as had originally been planned.

Luna 21 15 January 1973
This Soviet spacecraft landed on the Moon and carried a lunar rover, Lunokhod 2. It performed numerous experiments and sent back more than 80,000 images.

Luna 24 22 August 1976
This was the last of the Luna missions, landing near Mare Crisium to recover samples. It was the last spacecraft to have a soft landing on the Moon until 2013.

around 300,000 craters on the near side of the Moon that are wider than one kilometre (0.62 miles). The largest impact crater, called the South Pole-Aitken Basin, is about 2,500 kilometres (1,550 miles) in diameter and 13 kilometres (eight miles) deep. The biggest craters also tend to be the oldest, and many are covered in smaller craters. Younger craters have more sharply defined edges, while older ones are often softer and rounder. If the impact was especially large, material may be ejected from the surface to form secondary craters.

In some cases, the basalt eruptions flowed into or over large impact craters called basins. In general, the terrae have far more craters because the maria are younger in age than the terrae. While the Moon isn't much younger than Earth, our planet has processes that continue to change its surface over time, like erosion and plate tectonics. The Moon doesn't experience these, which is why some impact craters are up to 500 million years older than the basalt filling them.

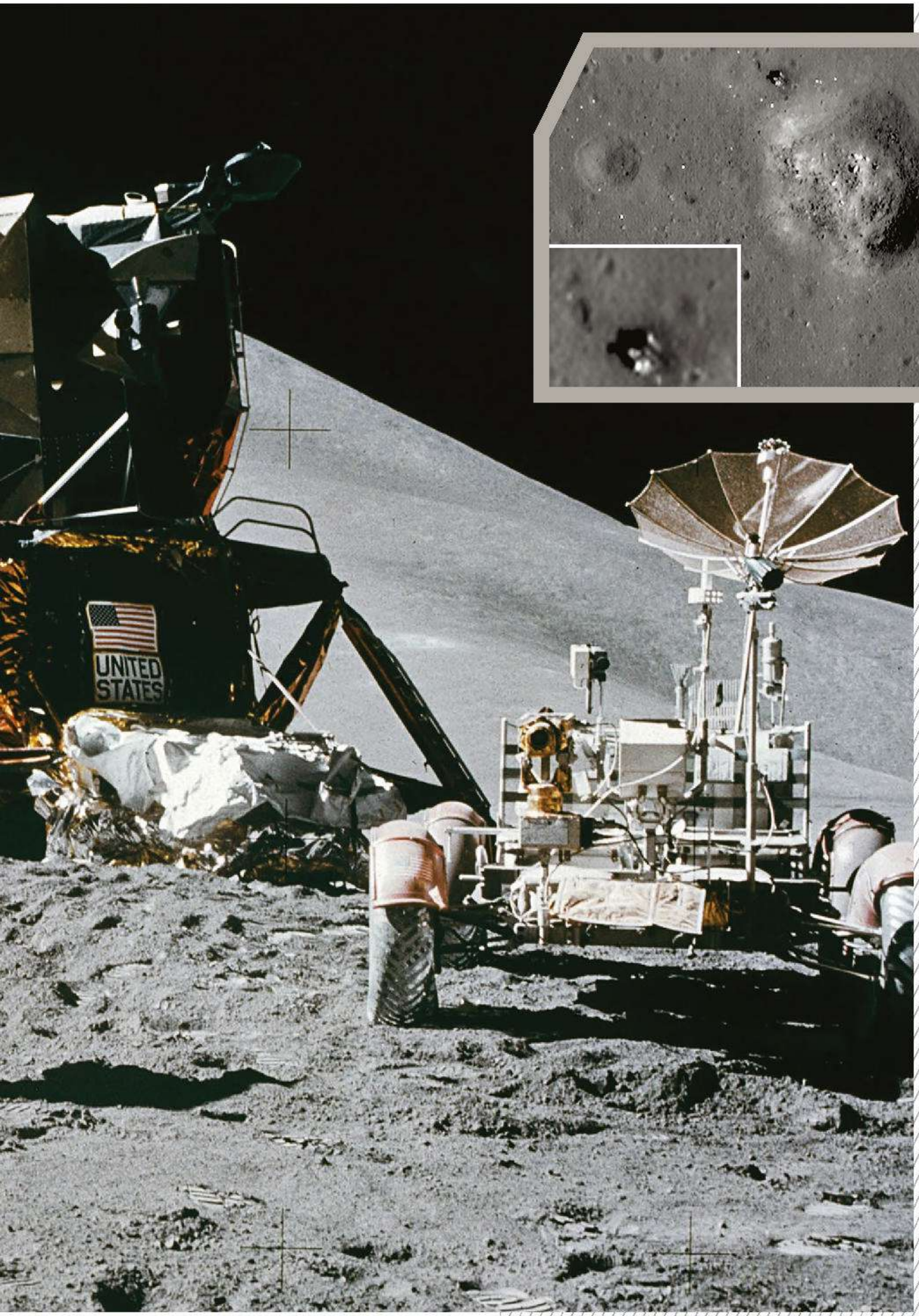
The loose soil on the Moon is called regolith. It's powdery and filled with small rocks. Over time, impacts from meteors, as well as space weathering (solar wind, cosmic rays, meteorite bombardment and other processes), break down the rocks and grind them into dust. Aside from the basalt and anorthosite rocks, there are also impact breccias – rock fragments that were welded together by meteor impacts – and glass globules from volcanic activity.

Although you may sometimes see the term 'lunar atmosphere', the Moon is actually considered to exist in a vacuum. There are particles suspended above the surface, but the density of the Moon's atmosphere is less than one hundred trillionth that of Earth's atmosphere. What little atmosphere there is gets quickly lost to outer space, and is constantly replenished. Two processes help to replenish the Moon's atmosphere: sputtering and outgassing. Sputtering occurs when sunlight, solar wind and meteors bombard the surface and eject particles. Outgassing comes from the radioactive decay of minerals in the crust and mantles, which can release gases like radon.

The Moon has a very minor axial tilt, so there aren't seasons in the same way that we have them here on Earth. However, temperatures on the Moon can change dramatically because there's no atmosphere to trap heat, and portions of the Moon may be either in full sunlight or total darkness depending on where it is in its rotation. Full sunlight can mean temperatures of greater than 100 degrees Celsius (212 degrees Fahrenheit). But at the end of the lunar day the temperature can drop by hundreds of degrees. There are also big differences in temperatures depending on the surface features. For example, the Moon is coldest in its deepest craters, which always remain in darkness. The coldest temperature ever recorded in the Solar System by a spacecraft was measured by the Lunar Reconnaissance Orbiter in the Hermite Crater near the Moon's north pole at -248 degrees Celsius (-414 degrees Fahrenheit).

©Getty: NASA

“Analysis of rock samples taken from the Moon during the Apollo missions showed that the Moon’s composition is almost identical to Earth’s”



The remains of Soviet probe Luna 24 rest in Mare Crisium

American boots on the Moon ended the Space Race

© NASA

EXPLORING THE MOON: PRESENT AND FUTURE

We've been studying the Moon for over 50 years, and thanks to a host of pioneering missions we now know more about our satellite than ever before

Although there hasn't been a manned mission to the Moon since 1972 and there were no soft landings at all until 1966, we're still exploring our satellite. Currently the Lunar Reconnaissance Orbiter (LRO) is still circling the Moon. It launched on 18 June 2009, and became the first NASA mission to the Moon in more than a decade. The LRO is meant to be a precursor to future manned missions, and was originally designed to spend just a year in orbit. However, the mission was extended several times. It was designed to extensively map the Moon in high resolution, explore the potential of ice in the polar regions, study the deep space radiation, and continue to map the surface of the Moon. The other current NASA mission is ARTEMIS, an extension of an earlier satellite mission. Two small probes have been orbiting the Moon together since summer 2011, having previously performed lunar and Earth flybys.

The Lunar Crater Observation and Sensing Satellite (LCROSS) was launched along with the LRO and considered an inexpensive way to look for water ice, and it was successful. The LCROSS discovered ice in the Cabeus crater near the Moon's south pole after its upper stage impacted as planned on 9 October 2009. Two small spacecraft under the name GRAIL A and GRAIL B were launched on 10 September 2011 and impacted on 17 December 2012, having collected data to help understand how terrestrial planets have evolved. Japan, India and China have all had lunar probes in the last six years as well.

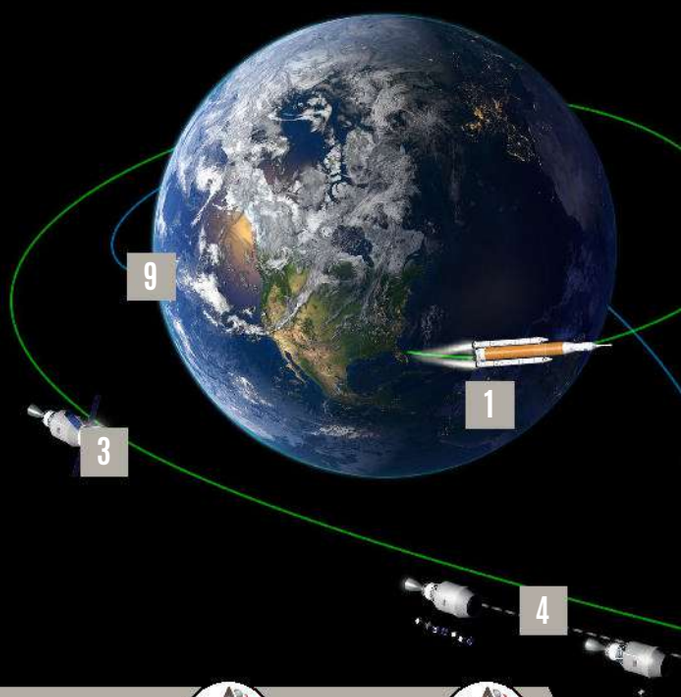
Humans will return to the Moon in 2025 and explore sites for a permanent base

EARTH TO THE MOON

Jump on board the Orion as we follow the route planned for the Artemis astronauts

1 Launch day
Scheduled to launch in 2025, the third Artemis mission and second with crew on board will launch from the Kennedy Space Center in Florida. It will be monitored by the nearby Launch Control Center.

2 Entering orbit
Once the rocket has taken Orion into orbit, its engines shut down and it will separate from the capsule. These rocket components will fall towards the Pacific Ocean. Orion will then deploy its solar arrays.



2022 Artemis I
The first mission will be uncrewed to test the takeoff and the capsule's ability to orbit, descend and splashdown. It will carry 13 small satellites to perform experiments and technology demonstrations. The craft will orbit the Moon for six days, collecting performance data.

2024 Artemis II
Carrying the first four Artemis astronauts, the Orion capsule will take the crew farther from Earth than humans have ever travelled before. Over the approximately ten-day mission, the crew will complete a lunar flyby and return to Earth, evaluating the performance of the spacecraft's systems.

2025 Artemis III
This will see the next man and first woman step onto the lunar surface. Providing previous missions have been successful, the astronauts will shoot towards the Moon, using the lunar lander to lower two people to the south polar region. They will remain on the Moon for around a week.

3 Trans-lunar injection
Having made it into Earth orbit, the Orion vehicle will head to the Moon. During a 20-minute burn, the engines will fire to increase the speed, displacing the spacecraft from its low-Earth orbit.

4 To deep space
Set on a precise trajectory, Orion will travel over 384,000 kilometres (239 miles). This needs to account for factors such as gravity and the movement of the Moon. Artemis I will have tested the planned path.

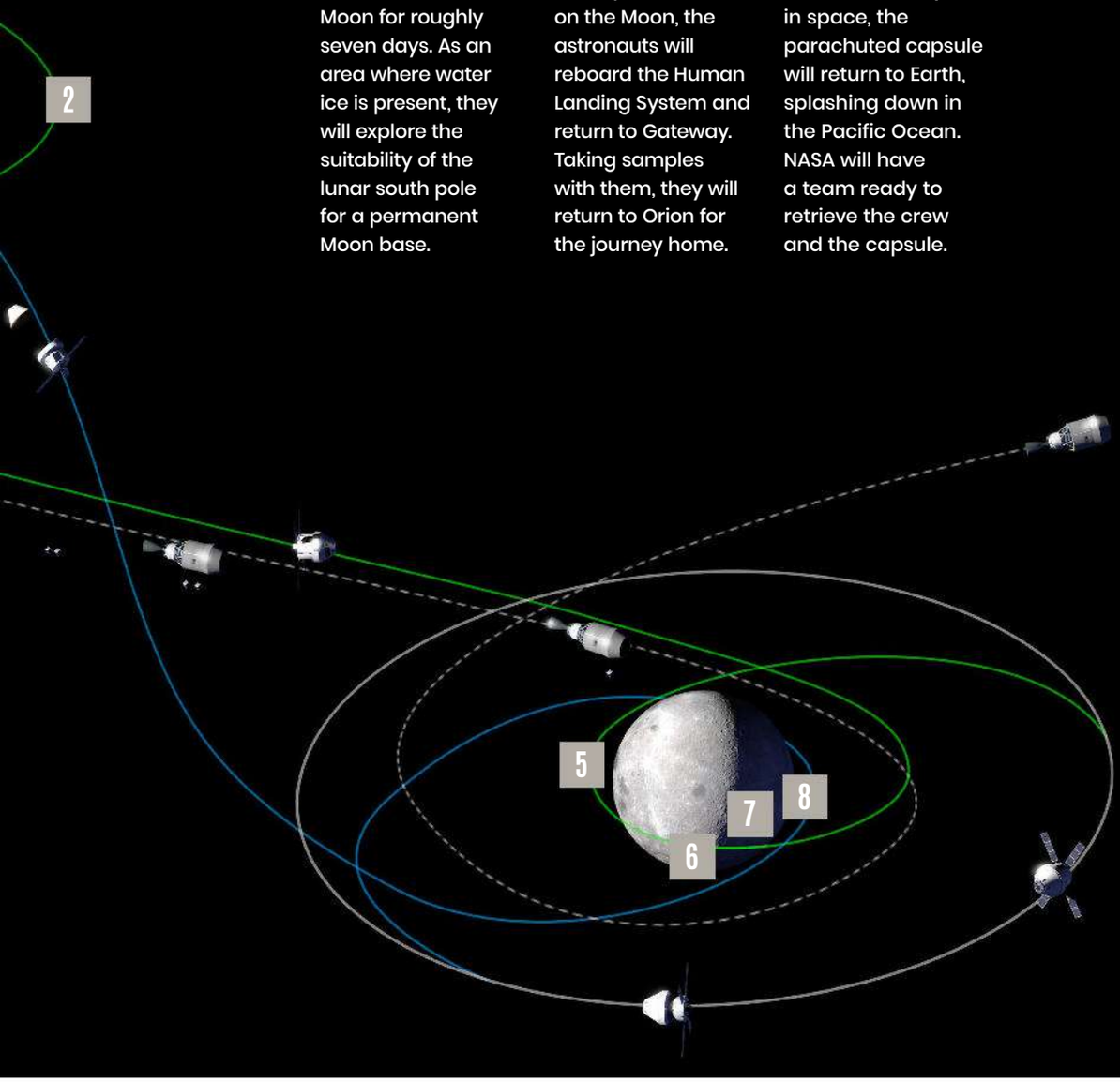
5 Lunar flyby
A main engine burn 185 kilometres (115 miles) above the Moon's surface will put Orion on a trajectory to intercept the orbit of the planned Lunar Gateway space station, set to launch in November 2024.

6 Moon landing
Having docked with Gateway, the crew may need to inspect it and collect supplies. While two astronauts will stay aboard the spacecraft in orbit, the other two will transfer to a lander vehicle.

7 Lunar exploration
The astronauts will remain on the Moon for roughly seven days. As an area where water ice is present, they will explore the suitability of the lunar south pole for a permanent Moon base.

8 Ascent
Having carried out experiments on the Moon, the astronauts will reboard the Human Landing System and return to Gateway. Taking samples with them, they will return to Orion for the journey home.

9 Splashdown
After spending less than 30 days in space, the parachuted capsule will return to Earth, splashing down in the Pacific Ocean. NASA will have a team ready to retrieve the crew and the capsule.



MAIN MISSION OBJECTIVES

Long-term presence
Following Apollo 17's three-day presence on the Moon, Artemis will send astronauts there for weeks.

Equality
A female astronaut hasn't set foot on the Moon yet. This mission will demonstrate the increasing role women have played in space missions since the Apollo era.

Partnerships
NASA has collaborated with private companies such as SpaceX and Boeing. These show space travel's shift towards commercialisation.

Technology
NASA is always learning from past missions; the spacecraft and spacesuits have been tailored to the Moon mission, exhibiting the latest in space technology.

Knowledge
Collecting further information about the lunar surface and deep space, NASA hopes to become better prepared for later missions back to the Moon and further afield.

Resources
Access to the lunar surface provides the opportunity to search for rare minerals and exploit resources. Hydrogen and oxygen could be used as rocket fuel to travel from the Moon.

SPACE FACTORIES

3D printing Moon bases, rockets and... food?

Every kilogram that must be hauled into space for a human crew represents one kilogram less that can be used for science experiments or instrumentation. More capable rockets is one solution to this problem. But what about actually making the components and food you need on site? The idea isn't as far-fetched as it sounds. The European Space Agency (ESA), NASA and others are testing out 3D printing as a way to manufacture structures, rocket parts and even pizza.

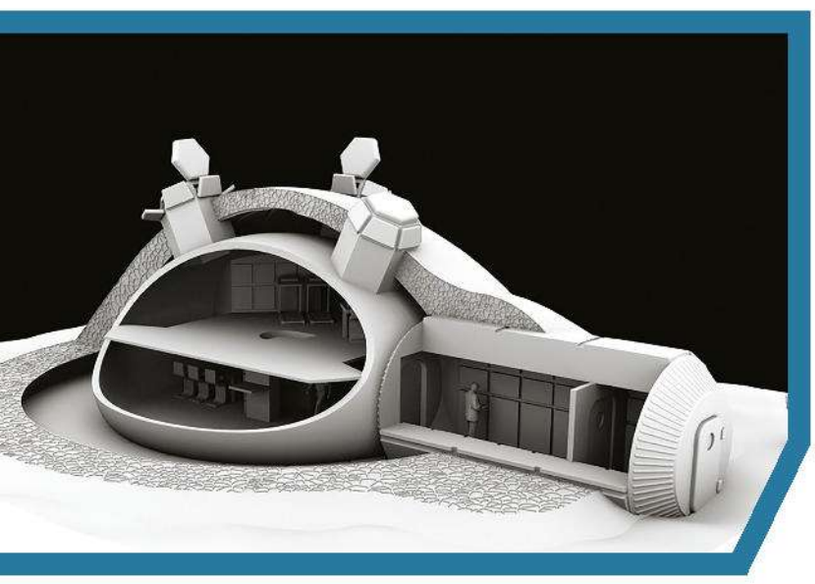
Looking ahead, the ESA has suggested that 3D printing could reduce the cost and complication of future lunar bases. "3D printing offers a potential means of facilitating lunar settlement with reduced logistics from Earth," said Scott Hovland, head of the Facilities and Technology Unit at the ESA. The first step is to find a structure that works. Astronauts could haul an inflatable dome with them, but they would still require a heavy shield to protect against radiation and micrometeoroids. A proposal from Foster + Partners suggests a shield with a structure similar to a bird's bones: lightweight hollow cavities with the strength to hold themselves up.

Structures are one issue, but feeding astronauts is a more pressing one. For those of us who know how full the fridge gets after only a few shopping trips, imagine how much would need to be hauled to survive months or years on the road. NASA gave a Phase 1 contract to Texan company Systems and Materials Research Consultancy to explore the possibility of making food in space. One of NASA's main aims is to "enable nutrient stability and provide a variety of foods from shelf stable ingredients. The food definitely has applications for space travel, but with NASA being an agency that advertises spin-offs, you can guarantee it's also thinking of Earthly applications for the technology. If food could be manufactured reliably and safely, imagine the difference it could make in handing out assistance in an area devastated by a hurricane, flood or other natural disaster. Countries that are also having regular problems feeding the populace through their own agriculture could supplement their own efforts with 3D-printed food. It's perhaps a little audacious to hope it could eliminate world hunger, but manufacturing food in this way would be a start towards it.

Or how about making rocket components out of 3D-printed technology? It could reduce the cost of space missions as it could lead to on-site printing, making it easier to manufacture. NASA and Florida's Aerojet Rocketdyne tested a rocket engine injector created through 3D printing. The tests went just fine: the agency and contractor put the component through a series of firings and were pleased with the results. If the process works in future tests, NASA says the injector could be made in a third of the time – four months instead of over a year with traditional processes – and cost 70 per cent less.

> **"3D printing offers a potential means of facilitating lunar settlement"**
> **Scott Hovland**

With its capabilities expanding, 3D printing provides a possible route to solving a lot of problems in space exploration, such as manufacturing things and hauling food and other items on long-distance voyages. Next is making sure there's a technician on hand to fix the printer off-planet if it breaks down.



Future Moon bases could be partially constructed from 3D-printed materials

1 Next-generation lunar base

This base would be a combination of an inflatable structure as well as a 3D-printed shield to prevent micrometeoroids and radiation from penetrating it.

2 Helping human exploration

3D printing is expected to make it easier for human missions to occur on the Moon, and other places outside of Earth.

3 Using local resources

Any manufacturing process on the Moon will likely make use of local resources such as the regolith, or lunar soil, to reduce the cost.

4 Machine making

It's possible that machines could even be partially or completely manufactured from 3D-printing processes using high-strength materials.

Foster + Partners created this 1.5-tonne building block using 3D printing

© ESA

BIO+

Martin Rees

Renowned Astronomer Royal Martin Rees is best known for his work on some of the most exotic and extreme objects in the cosmos: black holes, quasars, gamma-ray bursts and the early universe. He's written several books, has received numerous prestigious academic awards, was president of the Royal Astronomical Society and even has a seat in Britain's House of Lords as Baron Rees of Ludlow.

© Getty Images

Astronomer Royal Martin Rees

"The early universe was slightly lumpy"

All About Space speaks to the much-celebrated Astronomer Royal Martin Rees about his contributions to the Big Bang theory and life on other planets

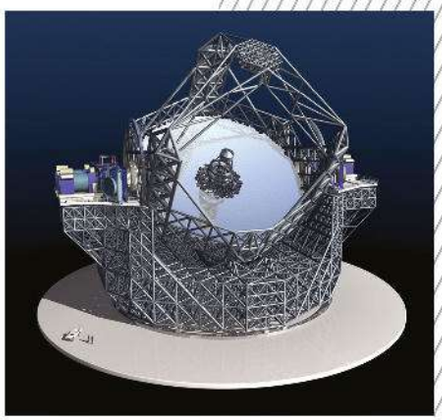
Interviewed by Ben Biggs

Tell us about your role as Astronomer Royal – what does it mean for you?
Astronomer Royal is just an honorary title given to someone that's active in astronomy now. It used to be the person who ran the Greenwich Observatory, and the title dates back to 1675. But the observatory has become a museum, and the title of Astronomer Royal is now given to a senior academic astronomer, no longer to the person that ran the Greenwich Observatory.

You've had this post for nearly 30 years; could you pick out a few highlights?
There have been some huge highlights in astronomy during that time. We've learnt a great deal about how the universe is expanding, that expansion is speeding up and not slowing down. I think the most exciting development for most of us has been the realisation that most of the stars in the sky have retinues of planets orbiting them. The night sky is really interesting because we know that every star is actually a planetary system.

What do you hope to see from the big telescopes of the future?
They're a big step forward from what we have now. It will be a big change when we have these larger ones. There are two being planned in America, plus the unimaginatively named Extremely Large Telescope (ELT), which plans to have a 39-metre mirror. That will have the capability to see very faint objects, and I'll be interested in looking as far back in time as we can and therefore as far away as we can. I'll be very interested in what it can do for planets around other stars because in order to take images of planets around another star you've got the problem of looking at a firefly very near to a searchlight, as it were, only much fainter.

The ELT will have the combination of collecting power and angular resolution to see them. It will enable astronomers using a high-level spectrograph to distinguish between the light of the star and the much smaller contribution coming from the reflected light of the planet, thereby learning something about the planet – whether it's got lots of clouds, topographical features, the length of the day and so on.



The ELT is currently under construction in Chile

What's your position on finding life on these planets, or indeed in the Solar System?

We don't really understand how life began on Earth. We understand how it evolved, with Darwinian selection, but we don't understand how the transition from complex chemistry to the first metabolising and reproducing systems occurred, whether it was a very rare fluke or something that would've happened anywhere given the right environment.

I think most of us would be very surprised if there was any past life anywhere in our Solar System: people are looking for evidence of past life on Mars, and there could be life under the ice of Enceladus or Europa. But that's very optimistic. It's very important to look for it because even if we were to find even the simplest form of life and we could be sure it occurred independently, that would straight away tell us that life must be very common in the galaxy.

Now we know that there are a billion planets rather like the Earth orbiting other stars in our galaxy, that makes everyone suspect that there's very likely to be life. We've no idea how likely it is, we've no idea how simple life would evolve into anything as complex as our biosphere or evolving intelligent creatures, but it's a very exciting prospect. In a decade or two, we're going to have clues to the answer.

Do you think it possible that life was seeded on Earth from other planets?

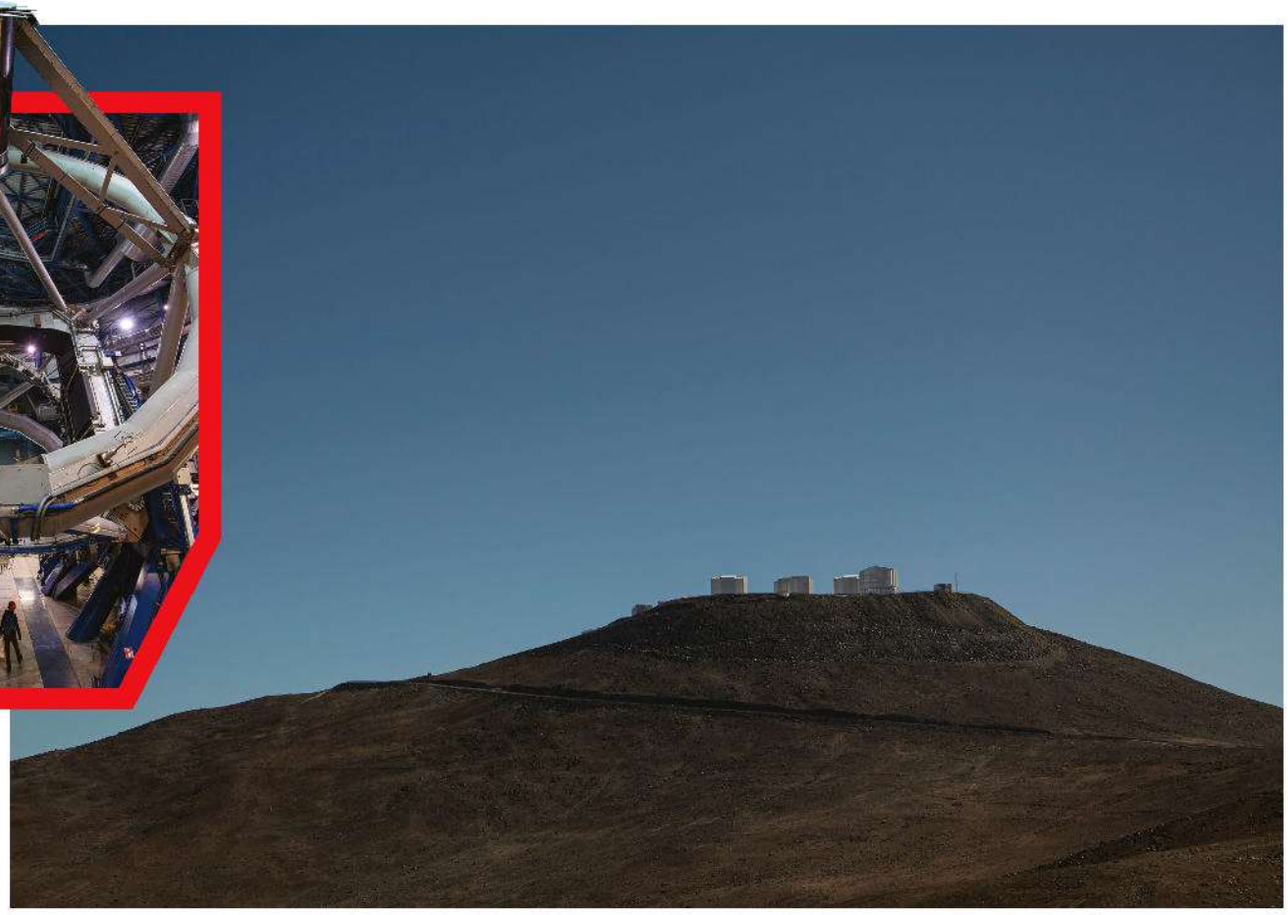
I think it's wrong to have any strong beliefs on these topics where it's very uncertain, but it seems to be slightly unlikely. It seems to be more likely that life on Earth started here, although it is indeed possible that life on Earth came from Mars. Even if we did find life on Mars, we wouldn't be sure whether it had the independent origin.

You've made notable contributions to our understanding of the cosmic microwave background and quasars; how has the universe changed for humankind since then?

I think it's important to realise that the progress made in the last few decades is 95 per cent due to the advances in instrumentation and only slightly due to theorists like myself. It's the experiments that have been marvellous in making advances in the subject. I think, as regards quasars and galaxies, we've come to understand that at the centre of a galaxy there is almost always a large black hole, and the size of the black hole is correlated with the size of the galaxy. That leads us to suspect that the formation and growth of the galaxy was somehow linked to the formation and growth of the black hole. This is one thing that many of us are trying to puzzle out. We've made a great deal of progress in understanding quasars; they're not just important in their own right, but they serve as probes for the intervening material. Quasars have enabled us to understand the history of the universe by allowing

Part of the Very Large Telescope (VLT) in Chile

Four 8.2-metre (26.9-foot) dishes make up the VLT



us to infer how much gas there was and how hot the gas was from the first billion years of the universe to the present. Then to understand how the first stars and galaxies formed and lit up the universe and what the subsequent history was. That's an important advance.

The other big advance has been understanding what happened long before galaxies formed, understanding the early phase of the Big Bang. It's been nearly 60 years since the so-called afterglow of creation – evidence for microwave radiation pervading all of space. Penzias and Wilson discovered that accidentally in 1964, and we now have very detailed observations of this radiation. In particular, we know it's not completely uniform over the sky. We've learned from a number of experiments, especially from the Planck satellite, about how the temperature varies a bit from place to place. That tells us that the early universe was slightly lumpy. It's rather like on an ocean where you have waves of different heights. Numerical calculations have shown that if the early universe was indeed lumpy in the way it's observed to be from the Planck data, gravity acted on those fluctuations, and then after 13 or 14 billion years the universe would actually look like ours does. We have a very good theory that the structures we see in our universe – the galaxies and clusters – have emerged by gravity acting on initial slight density irregularities present when the universe was young. That's a great achievement – it links the present universe to the very early universe.

Another big step forward has been to go back even further to understand why the universe, as observed by the Planck spacecraft, contains these fluctuations. And what's amazing here is that this takes us back to what happens in the first trillionth of a trillionth of a trillionth of a second, when everything we see out to the most distant galaxies was squeezed down to the size of a tennis ball. The fact that we can talk with a straight face about this is an extraordinary achievement. 60 years ago it wasn't clear whether there was a Big Bang at all, and now we know what the universe was like back to when it was a nanosecond old... it's amazing progress in understanding our origins.

You've written a book on the future of humanity, so do you think we need to move off this planet to survive even in the near future?
I hope there will be pioneers living away from Earth a century from now, but I think we mustn't kid ourselves that there's an easy way to escape from Earth. There's nowhere in our Solar System that's going to be a comfortable place to live. We can certainly say that it won't even be as comfortable as living at the South Pole, for instance. The idea that there will be mass emigration into space is really complete nonsense. The problems of Earth have to be solved here on Earth, and we can't escape from them. I think we can guarantee a bright future here on Earth, but it will be a bumpy ride through this century as technology becomes more powerful and humans selectively produce more challenges to the environment and climate of the planet. It's here that there are risks that I have written about and worry about. The more powerful technology gets, not only does it have an upside but a downside.

"The problems of Earth have to be solved here on Earth, and we can't escape from them"

Will humans escape Earth before its end?

You could compare it to some children playing with big, dangerous toys.
That's right. And I think we ought to make sure we don't unthinkingly cause global environmental damage. We've got to ensure that we don't have village idiots in a global village who can cause catastrophe by error or by terror.

You've received numerous awards for your work, but what's your proudest moment as an astronomer?
I wouldn't like to single out anything. I've been very fortunate to work in astronomy in this country as part of a very vibrant community. It's been wonderful. I'd like to add that I would have derived less satisfaction from being an astronomer if I could only talk to a few fellow specialists about it. It's a big bonus for us in astronomy that we can share our wonder of new discoveries with the wider public. I very much enjoy the interactions with the wider public of amateur astronomers and the more general public because they are fascinated by these discoveries. After all, the cosmos is part of our environment and the sky's the one feature that's been shared by all humans throughout human history.

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HYPERGIANT STARS

They're the biggest stars in the universe – cosmic monsters up to a million times brighter than the Sun – so how do supergiant and hypergiant stars push the limits of astrophysics?

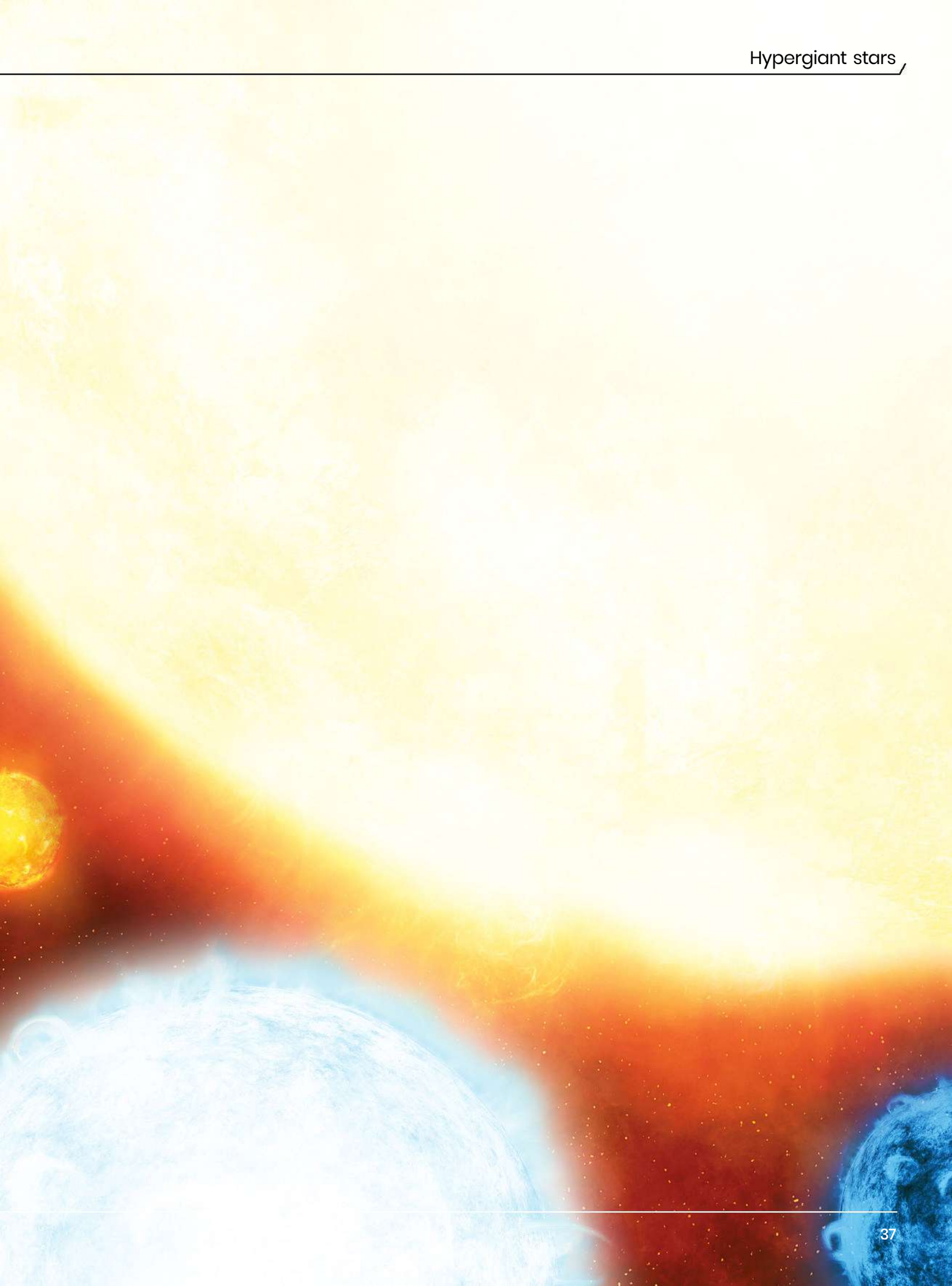
Written by Giles Sparrow

Look up at the sky on a dark night and you'll see hundreds of stars. But only a few will really stand out. For some it's simply because they're close to Earth. Sirius is just 8.6 light years away, so even though it's a fairly average star – though still 25 times more luminous than our Sun – it appears as the brightest star in our sky. But other stars appear bright because they really are. The second-brightest star in the sky, Canopus, is one such star – 310 light years from Earth and some 15,000 times more luminous than the Sun. Stars in this class are usually known as supergiants. They have the mass of ten or more Suns and evolve in a very different way from lower-mass 'Sun-like' stars, living fast, squandering their nuclear fuel and dying young in spectacular supernova explosions. The most massive stars of all, containing many tens or even hundreds of solar masses of material, are hypergiants, the most extreme stars known. "In astronomy I think there's a natural tendency to be attracted to extremes," explains Professor Paul Crowther from Sheffield University. "Whether that's the most extreme by physical size, which are generally the cool red supergiants, or the most extreme by mass, which are the hottest and brightest blue hypergiants." And Crowther should know – he's devoted much of his career to studying these stellar monsters and in 2010 discovered the most extreme hypergiant so far. It's a stellar beacon 165,000 light years from Earth in the independent Large Magellanic Cloud galaxy, an incredible 9 million times more luminous and 265 times more massive than the Sun.

Supergiants and hypergiants were first discovered through the theoretical tools of astronomy – in particular the Hertzsprung-Russell (H-R) diagram which allows astronomers to visualise the properties of stars en masse. However, the word 'giant' can be somewhat confusing because in this case it combines concepts of mass and size. The largest stars by diameter can all be loosely defined as 'red giants' – an evolutionary phase that most stars pass through near the end of their lives, during which they swell to huge diameters, and become far more luminous as they pump out more energy, but conversely turn red thanks to the coolness of their vast outer surfaces. The more massive a star is, the bigger it will grow as a red giant, and red supergiants with tens of solar masses – such as VY Canis Majoris, with a diameter larger than Jupiter's orbit around the Sun – are indeed the largest stars of all. However, really monstrous heavyweight stars never actually reach this stage, so while the larger a red giant is the more massive it will be, the most massive stars of all aren't actually the largest.

The most massive stars are born at the heart of collapsing star-forming nebulae, where gas and dust are most readily available. Unlike the more sedate, Sun-like

"The borderland between supergiants and hypergiants is filled with unusual stars"



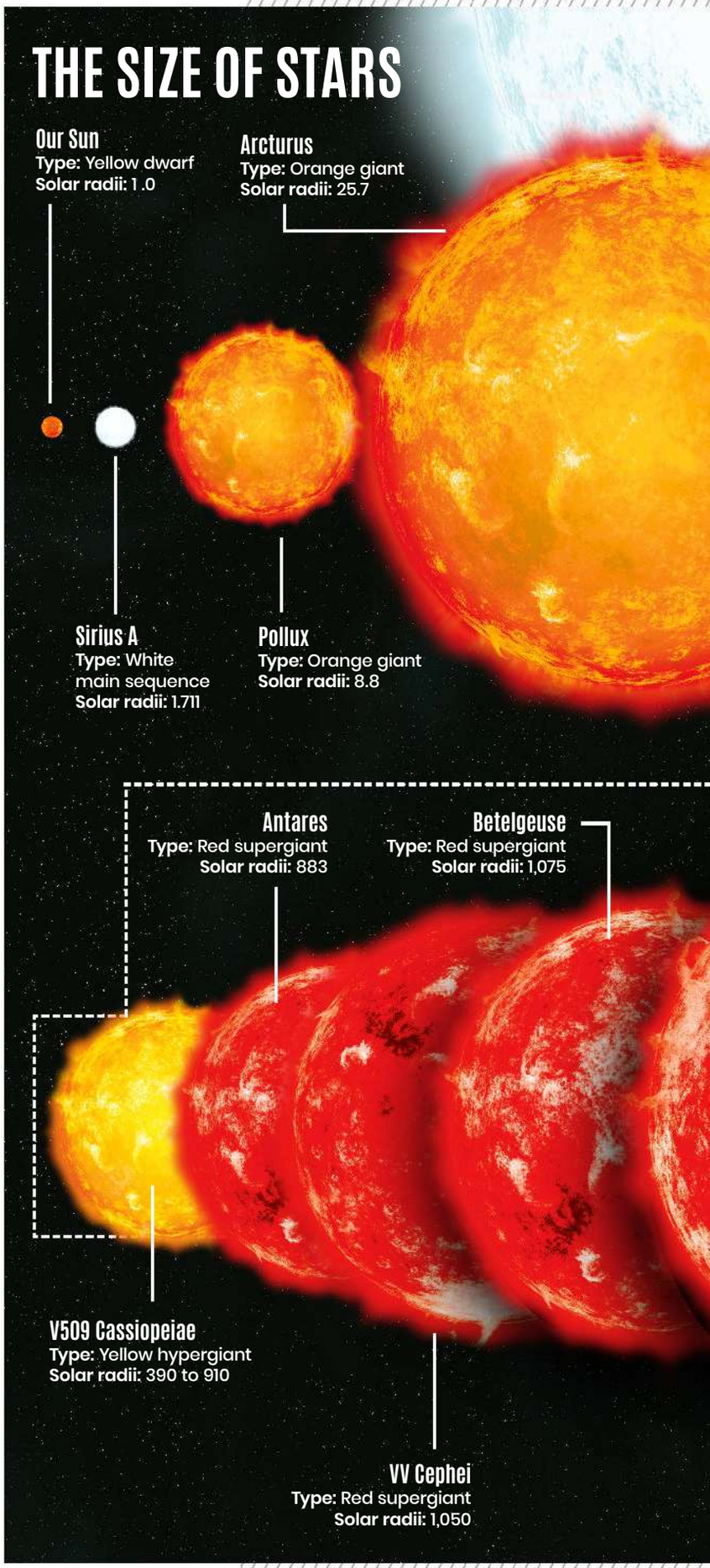
stars, which form around the edges and coalesce over many millions of years, these stellar heavyweights grow to their enormous proportions in just 100,000 years. The overall amount of raw material in the nebula also has a role to play. "There seems to be a broad relationship between the total mass of a cluster and the most massive star within it – so for instance the Orion Nebula has a mass of 1,000 Suns, and its most massive stars are about 30 times that of the Sun, while the NGC 3603 cluster has about 10,000 solar masses of material and its most massive stars weigh around 100 solar masses. We don't know quite why this 'mass function' is the way it is in young star clusters, but it seems to be a universal rule," says Crowther.

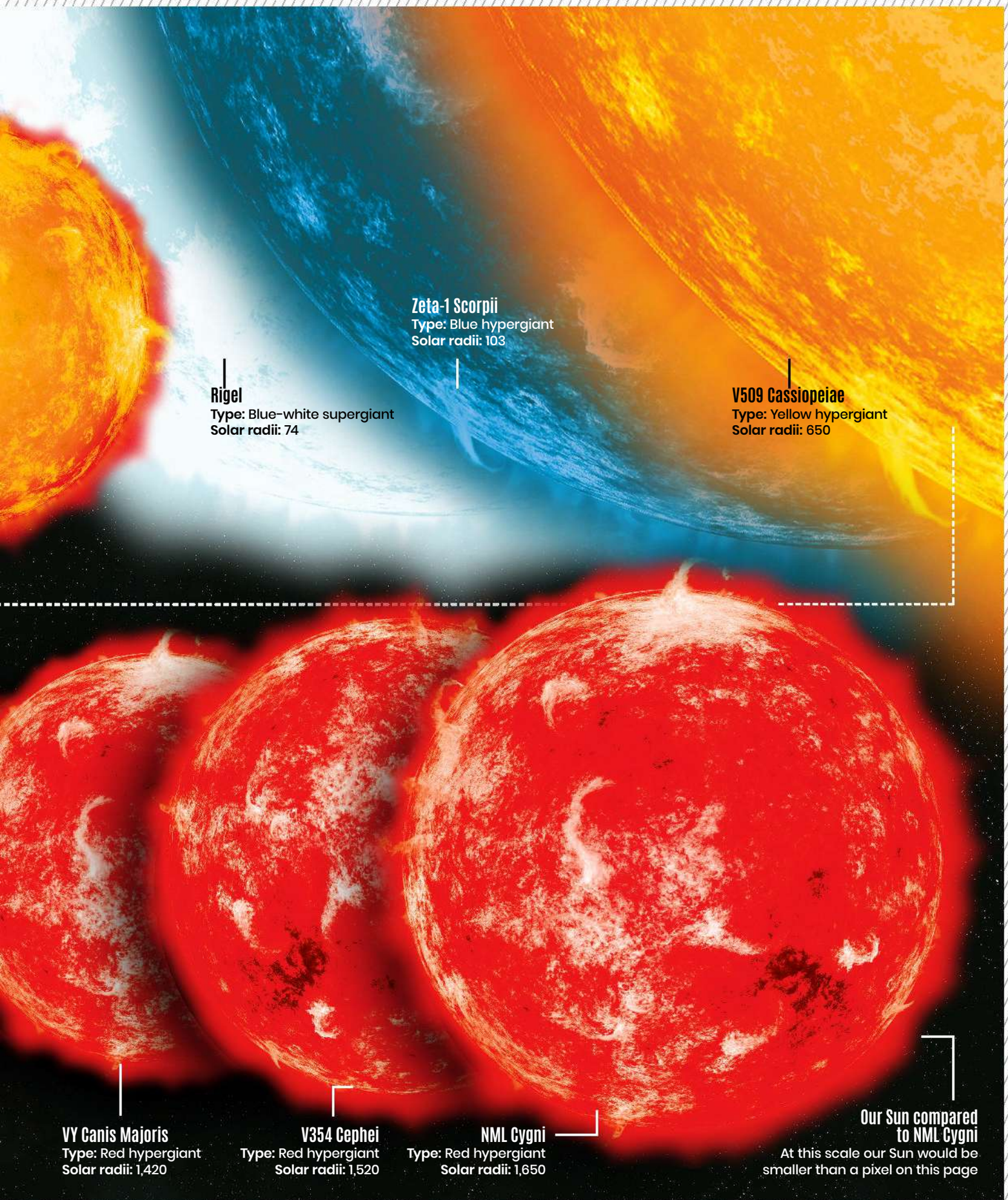
Competition between the massive central stars seems to act as a throttle to the formation process, ensuring that really massive stars are increasingly rare. "The next obvious question is whether if you had an even more massive cluster, would the mass of its biggest star keep going higher?" says Crowther. "And the answer seems to be no – we suspect there's a limit and it's linked to the star formation process. A star forms in a collapsing nebula full of competing stellar 'seeds', and it has a limited time to grab as much material as it can, or else its neighbours will. It's a bit like throwing a handful of sweets into a crowd of children – the ones nearest the centre will grab most of them really quickly, while those at the edges hardly get any. It's a competitive environment and that probably puts an upper limit on how massive a star can get."

"Supergiants simply don't live long enough to make it out of their stellar nurseries"

Another major difference between normal and monster stars lies in the nuclear reactions that keep them shining. In low-mass stars, these reactions are dominated by the 'proton-proton (p-p) chain', a process in which individual hydrogen nuclei fuse together one reaction at a time to eventually produce nuclei of helium, the next heaviest element. The p-p chain releases small amounts of energy at every step but proceeds relatively slowly, allowing Sun-like stars to keep shining for billions of years. In more massive stars, however, another process called the CNO cycle becomes important. This fusion chain also converts hydrogen nuclei into helium but it uses carbon nuclei as a sort of 'catalyst', allowing the reactions to happen at a much faster rate. The CNO cycle becomes increasingly dominant at higher temperatures and densities, and causes heavyweight stars to shine many thousands of times more brightly than their less massive neighbours. But the price for this brilliance is a drastically shortened life span – even though their cores contain much more nuclear fuel than those of Sun-like stars, massive stars exhaust themselves in just a few million years and begin to swell into supergiants or hypergiants.

This short life span means that supergiants are almost always found at the heart of newborn star clusters – these clusters disintegrate over millions of years, eventually scattering their longer-lived stars over




Zeta-1 Scorpii
Type: Blue hypergiant
Solar radii: 103
Rigel
Type: Blue-white supergiant
Solar radii: 74
V509 Cassiopeiae
Type: Yellow hypergiant
Solar radii: 650
VY Canis Majoris
Type: Red hypergiant
Solar radii: 1,420
V354 Cephei
Type: Red hypergiant
Solar radii: 1,520
NML Cygni
Type: Red hypergiant
Solar radii: 1,650
Our Sun compared to NML Cygni
At this scale our Sun would be smaller than a pixel on this page

GIANT STARS

Red supergiant

The biggest red giants are the largest stars in the universe, swollen to diameters of a billion kilometres or more by changes in their cores as they near the end of their lives. As they swell in size and brighten to hundreds of thousands of times solar luminosity, their surfaces cool to a distinctive red colour. But many scientists say these stars are supergiants rather than true hypergiants.

Yellow supergiant

These seem to be a rare intermediate stage. They seem to be red supergiants that have shed large amounts of their outer gas as they head towards a supernova explosion. In this photo of the 'Fried Egg Nebula', rings of ejected material can be seen surrounding the central star.

Blue hypergiant

These are the real heavyweights of the universe – tens or even hundreds of times more massive than the Sun and millions of times more luminous. Their powerful gravity limits their size, so their surfaces are intensely hot. Young star cluster NGC 3603 contains one binary system whose stars contain a staggering 90 and 120 solar masses of material.

This image shows a spiral structure in the material around R Sculptoris

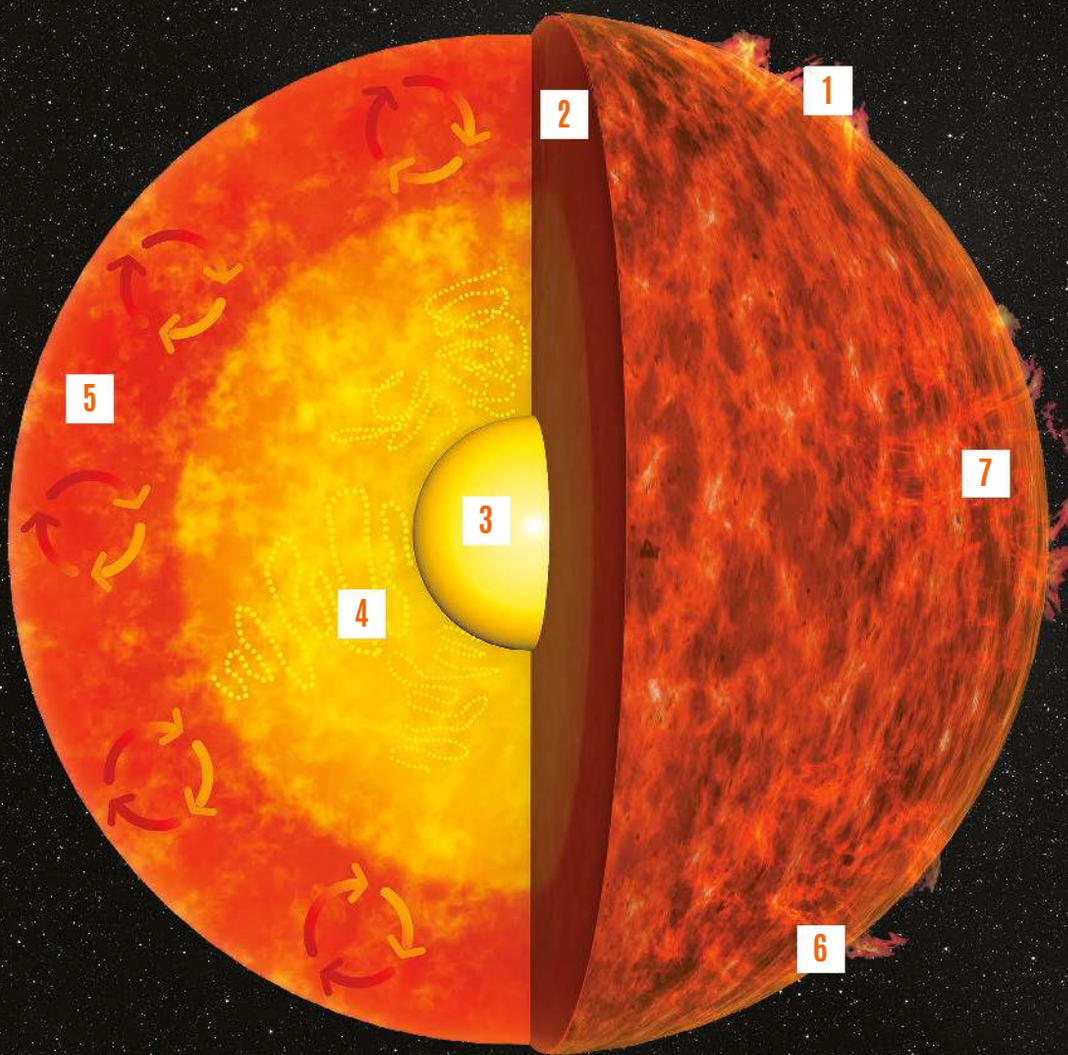
a broad region of space, but supergiants simply don't live long enough to make it out of their stellar nurseries. "These stars are incredibly rare. They only form in a few places and have very short lifetimes, so even if you find a star cluster that's just 5 million years old, its most massive stars will already have died," says Crowther. "There's only a handful of really young, massive clusters close enough to Earth for us to look for these guys and they're losing mass at a terrific rate, so the mass we measure depends on just how old the stars happen to be. The places where you usually find these really massive clusters tend to have enhanced star formation rates, usually due to galactic collisions or interactions."

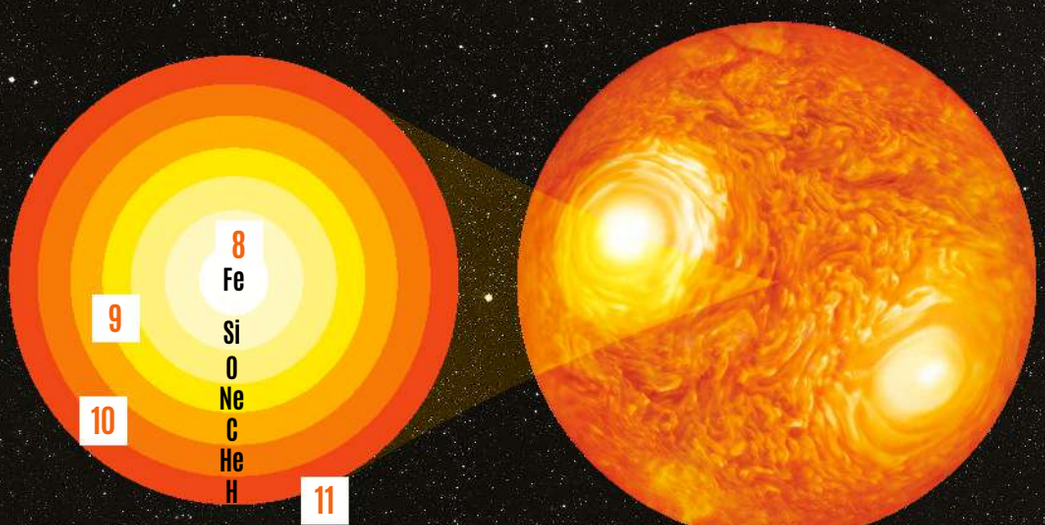
So what do supergiants and hypergiants look like? The truth is that they're surprisingly varied – while the H-R diagram might suggest that they'd all have extremely hot surfaces and appear blue in colour, in reality they range across the spectrum of colours. Supergiants show the most variety, and it seems that their colours simply reflect the precise balance between the inward pull of gravity and the outward pressure generated by its radiation at a particular phase in their lives. This balancing act, known as hydrostatic equilibrium, governs a star's overall diameter and therefore its surface area: even highly luminous stars can display Sun-like yellow or even cooler red surfaces if they are large enough for the heating effect of their escaping radiation to be thinly spread.

Most stars retain more or less the same mass throughout their lives and therefore maintain the same gravity, so their equilibrium is mostly affected by changes to their luminosity as the nuclear reactions in their cores change and evolve. From this, we can work out that blue supergiants are still close to the 'main sequence' of stellar evolution, while yellow ones have begun to swell in size as they reach the end of their lives. Red supergiants are even further along their life cycle and are the largest stars of all. But for really massive hypergiant stars, there's a different story. These stars never make it across to the red side of the H-R diagram – instead their brilliant radiation generates such huge pressure that it blows their outer layers away into space, exposing the interior and ensuring that such stars remain hot, maintaining blue or white-hot surfaces throughout their lives. This strong outflow of hydrogen-rich material gives itself away in a hypergiant's spectrum and is one of the key means of distinguishing them from really bright supergiants.

The borderland between supergiants and hypergiants is filled with a strange variety of unusual stars, and no two astronomers really agree on the precise dividing lines between them. For example, luminous blue variables are extremely bright stars that show long, slow changes in brightness with occasional outbursts, and include both supergiant and hypergiant stars. Most of the rare so-called 'yellow hypergiants',

STRUCTURE OF A SUPERGIANT





1 Red supergiant
A high-mass star that is nearing the end of its life and has long since exhausted the supplies of hydrogen fuel for fusion in its core.

2 Monster star
The largest red supergiants can grow to diameters larger than Jupiter's orbit around the Sun.

3 Still burning
The star's core keeps generating energy by fusion of heavier elements, growing denser over time.

4 Fusion shells
Meanwhile, nuclear fusion of lighter elements spreads out in a series of shells around the core.

5 Outer envelope
The huge amounts of energy coming from the core and its surrounding shells cause the star's upper layers to balloon in size.

6 Cool surface
The star's size gives it a huge surface area, so despite pumping out huge amounts of energy the surface stays cool and appears red.

7 Convection cells
Currents within the outer envelope form rising and sinking masses of hot and cool gas, giving the surface a blotchy appearance.

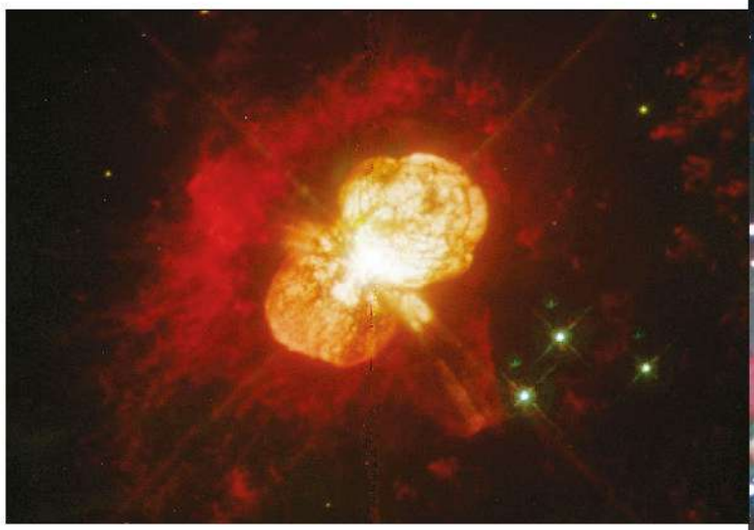
8 Iron core
Before the star dies, a core of solid iron begins to build up. Unlike lighter elements, iron fusion absorbs rather than releases energy, triggering the core's collapse.

9 Heavier shells
Closer to the core, heavy elements continue to fuse into still heavier ones, allowing the supergiant to keep shining.

10 Helium fusion
A second shell of helium fusion follows the hydrogen shell out, creating heavy elements.

11 Hydrogen fusion shell
Changes in the star's density and temperature allow hydrogen fusion to continue around the core after hydrogen in the centre has been exhausted.

© ESO; Getty



A Eta Carinae is 7,500 to 8,000 light years away

B Thor's Helmet in Canis Major

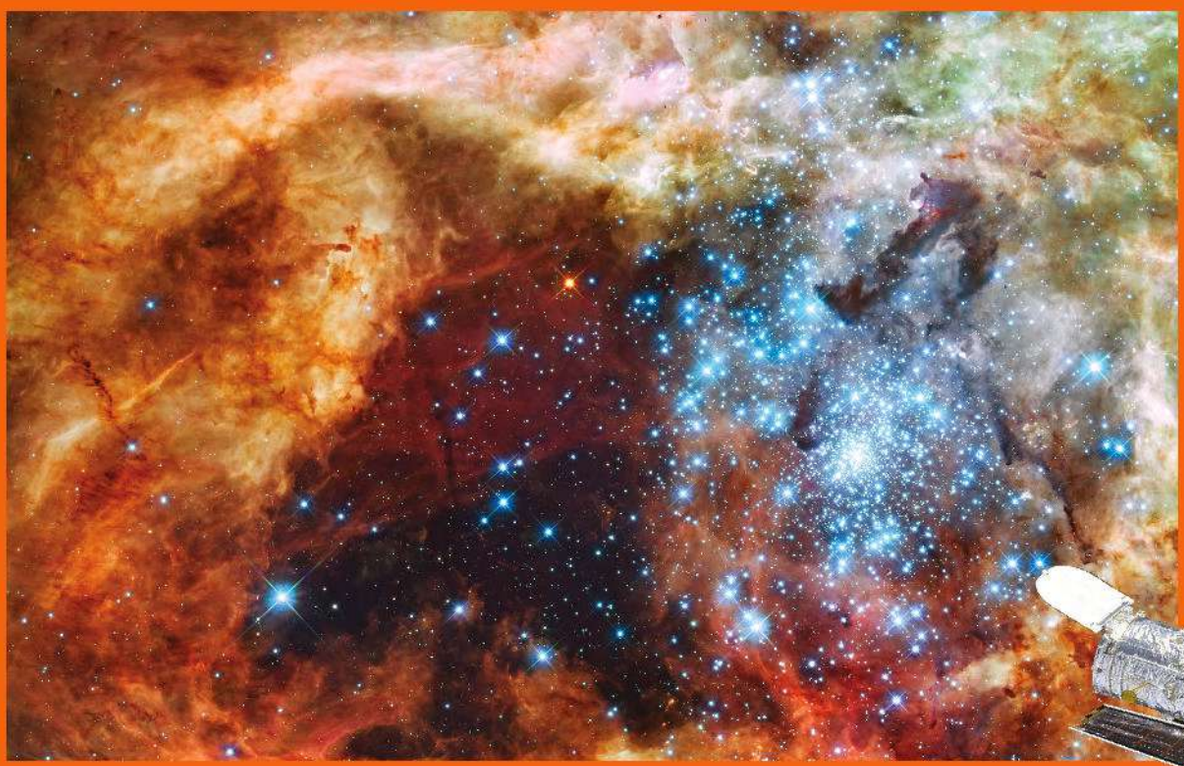
despite their name, actually seem to be red supergiants that are shedding their outer layers and heating up. And, as we've seen, astronomers also differ about whether red hypergiants even exist! Depending on their features displayed in their light, other categories of supergiant or hypergiant bear exotic names such as Wolf-Rayet stars and Ofpe stars. However, until recently the only certain means of weighing really massive stars, and identifying supergiants and hypergiants, was to pick them out in binary systems. Here, the orbital motions of the two stars can be used to calculate their masses. Fortunately, a recent breakthrough in modelling the behaviour of really high-mass stars promises to remove some of these limitations.

Giant stars live fast and die young, but what fate awaits them at the end of their lives? Once a star has exhausted the hydrogen fuel in its core, it has reached the end of its main sequence lifetime and can only continue to shine by burning hydrogen from the shell surrounding the core and heavier elements in the core itself. These processes cause the dying star to brighten and swell, shifting it towards 'red supergiant' territory, while its core develops a complex layered structure of increasingly heavy elements. Each new phase of fusion produces less energy than the previous one, and is exhausted more quickly, but the radiation that continues to pour from the core still helps to support it against its own enormous gravity.

That all changes when the star attempts to fuse iron – the first element whose fusion absorbs energy. The star's power supply abruptly falters and dies, and the huge weight of its outer layers comes crashing down. In what is known as a 'core-collapse supernova', the iron-rich core is compressed to a tiny size, while a huge shock wave rebounds through the remainder of the star, heating and compressing it until the whole star ignites in a blaze of nuclear fusion that may last for months and outshine a billion stars. As the supernova fades and the debris clears, the compressed remains of the core may be revealed as a super-dense neutron star, or even a black hole.

For the most massive stars of all, there may be a third option. "Theorists tell us that if a star dies with roughly 200 solar masses of material remaining, it could just blow up. It wouldn't be the usual core-collapse event, but a 'pair-instability supernova', which would blow itself to bits before it could form a super-dense core. These things would be amazingly bright and there have been a few observations of events that might be this kind of superluminous supernova." While they may be rare, these monster stars are certainly making their presence felt – and interest is only likely to increase in the next few years. Astronomers believe that supergiants and hypergiants would have been far more widespread in the early universe, when the lack of heavy elements would have given them a more compact structure with a hotter surface. Thanks to the expansion of the universe, the ultraviolet radiation that poured from the surface of these superhot stars should now be stretched or 'Doppler-shifted' to infrared wavelengths. Here it should be visible to NASA's James Webb Space Telescope, which launched in 2021 to give us our first view of the earliest stellar generations.

Giles Sparrow
Space science writer
Giles has degrees in astronomy and science communication and has written many books and articles on all aspects of the universe.



R136a1 was discovered in the massive young star cluster R136 which resides in the Tarantula Nebula, a turbulent star-birth region in the Large Magellanic Cloud dwarf galaxy

Hubble can be used to resolve separate stars

SEARCHING FOR MONSTER STARS

In 2010, Crowther and his team discovered R136a1, the most massive single star known at the time

What drew you to the R136 star cluster?
It's probably the prime target for anyone looking for the most massive stars – it's the most obvious place to look really because it's the most massive young star cluster in our part of the universe. It's about the same size as the Orion Nebula, but while that's got a couple of thousand stars, R136 probably contains 100,000 stars or more, if you could see them all. It's been known about for a long time, but the exciting thing is that now, with Hubble and large ground-based telescopes, we can resolve separate stars and look at them individually.

There's a really tight knot of stars at the cluster's centre called R136a?
There were claims that R136a was a single supermassive star thousands of times more massive than the Sun. But about 25 years ago astronomers confirmed that it was actually a cluster and now, thanks to technological advances, we can finally analyse the individual stars within it. When our team looked at it with the European Southern Observatory's Very Large Telescope in Chile, we were actually looking for binary stars, hoping we could use them to measure the masses of stars directly. We didn't find any binaries, but we did find that the individual stars in the cluster, and the brightest one in particular, are far more exceptional than anyone thought.

How do you work out the mass of a giant single star like R136a1?
First, you work out the star's luminosity, but that's a problem in itself. If you're looking at a yellow star with the same surface temperature as the Sun, then it's fairly straightforward – you're seeing most of the radiation in the optical and can work out the total energy output quite easily. Red stars such as cool supergiants emit only a tiny fraction of their energy as visible light, but you can still measure them in the infrared. The challenge with hot stars like R136a1 is that the energy's coming out in the ultraviolet, at wavelengths that get soaked up by the interstellar medium on their way to Earth. We can't measure the star's peak energy directly, so we have to infer it through other features of its light. Even once you've got an idea of the star's temperature and its overall luminosity, you still have to go an extra leg to get a mass. On the main sequence there's a clean relationship: the more luminous a star, the more massive it is. So for R136a1, where we came up with a luminosity not far off 10 million times that of the Sun, we asked our colleagues to work out evolutionary models for what the expected mass would be. That's how we got the figure of 265 solar masses.

Is it possible to check that result?
You're relying on one method to get a temperature, another to get a mass, and so on... The figures are not backed up by enough evidence to prove it, so we looked for another example of a similar star to prove the technique. Ideally we were looking for a star in a close eclipsing binary system, which would let us work out the mass. We found one in a cluster called NGC 3603, about 25,000 light years from Earth. That's now the most massive star system to be confirmed through the laws of orbital motion – it's got two stars in an orbit of about four days, with masses of 120 and 90 Suns. Once we'd got those numbers for that system, we used them to test our temperature and luminosity-based method, and we got basically the right answer.

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FOCUS ON

WEBB SNIFFS OUT AN ALIEN WORLD'S CARBON DIOXIDE

No telescope has ever detected carbon dioxide in an exoplanet atmosphere before

Reported by Tereza Pultarova

The James Webb Space Telescope has detected carbon dioxide in the atmosphere of an exoplanet in a breakthrough discovery that will usher in a new era of research on worlds outside our Solar System. The detection came during Webb's first campaign focusing on exoplanets, planets orbiting other stars. The observations targeted a hot gas giant called WASP-39b, located some 700 light years away from Earth in the constellation Virgo.

The planet, about as massive as Saturn but larger than Jupiter in size, had previously been observed by the Hubble Space Telescope in optical wavelengths and the now-retired Spitzer Space Telescope, which like Webb observed heat-carrying infrared wavelengths. Previous observations revealed the presence of water vapour, sodium and potassium in the planet's atmosphere, but it wasn't until Webb that scientists caught the signature of carbon dioxide. "As soon as the data appeared on my screen, the whopping carbon dioxide feature grabbed me," Zafar Rustamkulov, a graduate student at Johns Hopkins University in Baltimore and a member of the transiting exoplanet team which undertook this investigation, said. "It was a special moment, crossing an important threshold in exoplanet sciences."

Carbon dioxide has never been detected on any exoplanet before. Astronomers hope that the compound can help them better understand the formation history and evolution of the planets where it's found. "This unequivocal detection of carbon dioxide is a major milestone for exoplanet atmosphere characterisation," Laura Kreidberg, department director at the Max Planck Institute for Astronomy in Germany and co-author of a paper describing the discovery, said. "Carbon dioxide helps us measure the complete carbon and oxygen inventory of the atmosphere, which is highly sensitive to the conditions in the disc where the planet formed." Such measurements can help identify how far from its star the planet formed and determine how much solid and gaseous material it accumulated as it migrated to its current location.

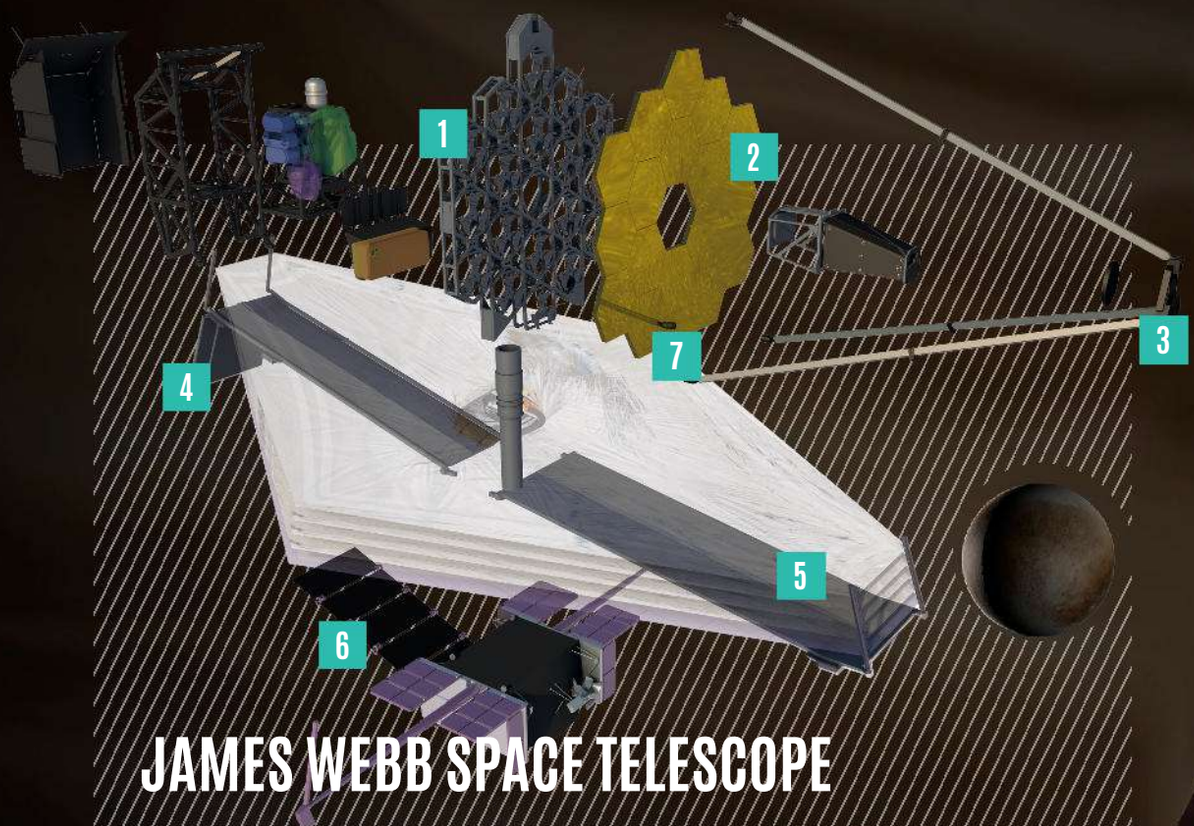
The discovery was made using Webb's NIRSpec instrument, a highly sensitive spectrograph that splits incoming light into barcode-like spectra that reveal how the observed objects absorb light. But neither Webb nor any other existing telescope can capture direct images of an exoplanet or its atmosphere. Instead, researchers compare observations of the star's typical light to light seen through the atmosphere as the planet passes in front of it. The measurements of WASP-39b were gathered on 10 July.

The researchers believe the telescope will be able to detect carbon dioxide in the atmospheres of other types of planets – including Earth-like rocky bodies – scattered across the galaxy. "The exoplanet community has been searching for the signature of carbon dioxide for decades," Kreidberg said. "With the extraordinary new capability of Webb, it will be possible to routinely detect carbon dioxide for hot Jupiters, as well as smaller, cooler planets more like Earth."

WASP-39b orbits extremely close to its parent star, WASP-39, less than five per cent the distance between Earth and the Sun, completing one orbit about every four Earth days. The planetwas discovered in 2011 and can only be observed through the transits it makes around WASP-39, which cause brief dips in the star's brightness.

"The exoplanet community has been searching for the signature of carbon dioxide for decades"

Laura Kreidberg



JAMES WEBB SPACE TELESCOPE

1 Integrated Science Instrument Module
Cameras and science instruments are housed in a module behind the primary mirror.

2 Primary mirror
18 hexagonal segments made of gold-coated beryllium are used to capture faint infrared light.

3 Secondary mirror
This mirror reflects light gathered from the primary mirror into the science instruments.

4 Trim flap
This ensures that the spacecraft is stabilised.

5 Multilayer Sun shield
Five layers protect the observatory from light, radiation and heat.

6 Solar power array
The array always faces the Sun, allowing sunlight to be converted into electricity.

7 Massive mirror
Each of Webb's segments measures 1.3 metres (4.2 feet) across – about the size of a coffee table.

©Getty Images

STAR PROFILE

THE SUN

The Solar System would be nothing if it weren't for the power and influence of our nearest star

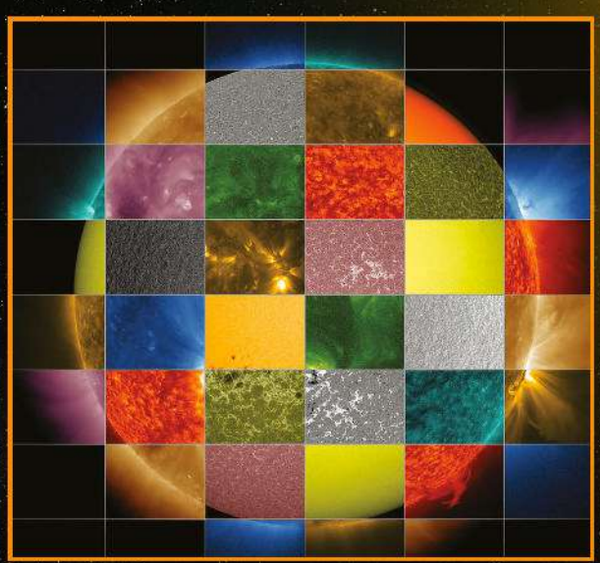
The Milky Way is home to billions of stars, and the universe is home to billions of galaxies. Our star, the Sun, has created a residential spot we call the Solar System. The Sun is the true centre of the Solar System: not only does everything else orbit around it, from asteroids to gas giants, but it makes up 99.8 per cent of the Solar System's mass and is 108 times the diameter of Earth.

This colossus was formed 4.6 billion years ago from a cloud of dust and gas. After this cloud began to rotate and collapse, it took 50 million years to form and become the star it is today. This was the point where the core of the star reached pressures and temperatures so intense that nuclear fusion was ignited. This ignition kick-started the formation of helium from hydrogen, releasing radiation that provides Earth with light, warmth, power and so much more.

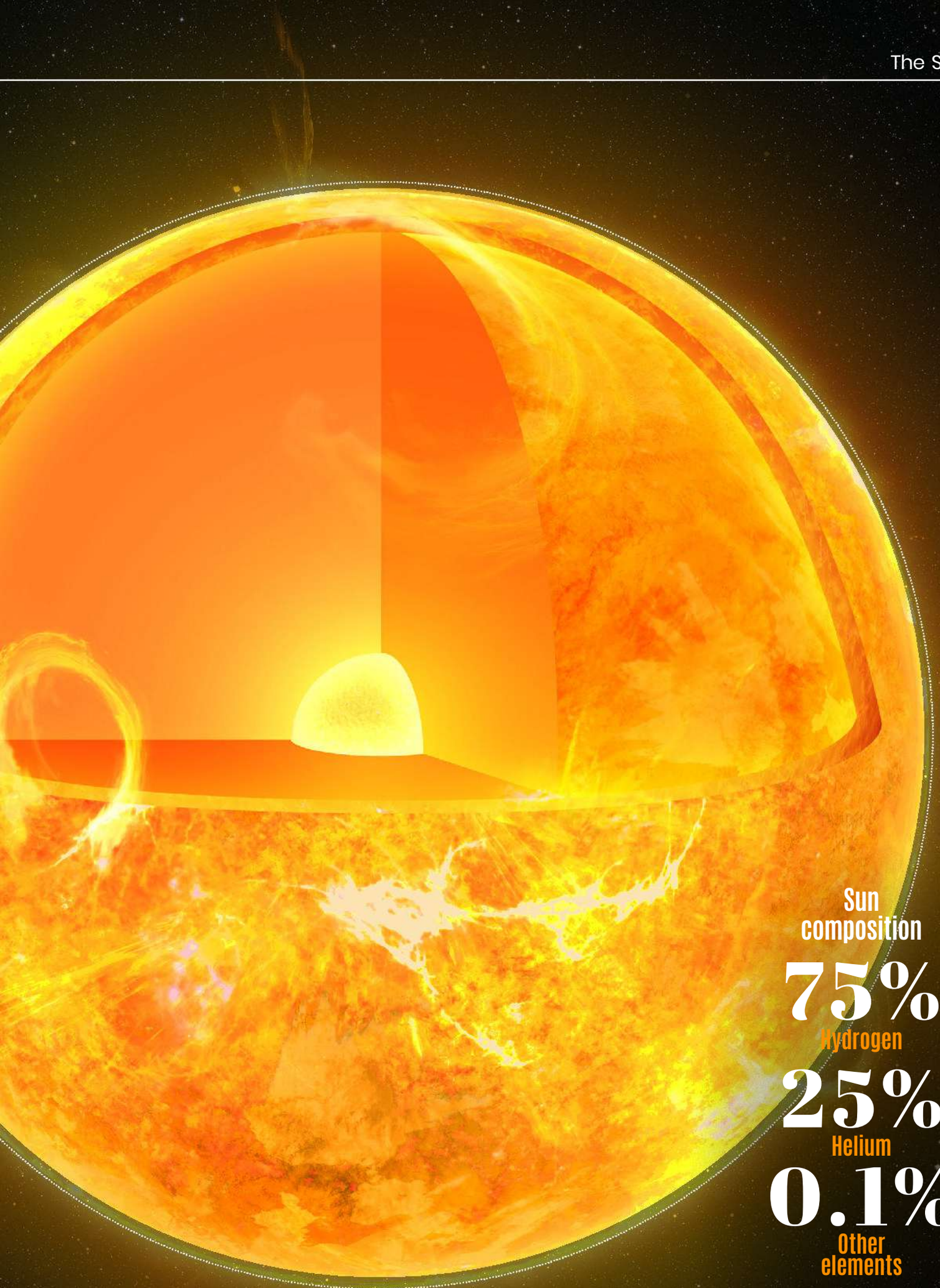
At the start of the Sun's life, planets and everything else in orbit were still forming from the leftover debris that began to fragment. The Sun has been in its mature state for nearly 5 billion years, and it will continue to be for another 5 billion years. After this the hydrogen will run out and the Sun will look to form heavier elements such as carbon, oxygen and so on. When this happens the radiation output will be greater than its gravity and it will swell into a red giant, swallowing Mercury and Venus and evaporating all the water and life on Earth. Afterwards the outer layers will be expelled into the cosmos, and what will be left is a white dwarf star.

The Sun has several zones within its interior and atmosphere, starting with a core that burns at over 15 million degrees Celsius (27 million degrees Fahrenheit). This takes up roughly a quarter of the distance to the surface, and outside the core are the radiation and then the convection zones. The coldest layer of the Sun is the photosphere – the visible surface. This is between 6,125 and 4,125 degrees Celsius (11,000 and 7,460 degrees Fahrenheit). Next is the chromosphere and the mysterious corona, invisible without the aid of an eclipse. The corona's temperature ranges from 1 to 10 million degrees Celsius (1.7 to 17 million degrees Fahrenheit), and is perplexing to astronomers because it gets hotter the further away from the Sun you are.

The activity of the Sun creates a magnetic field that permeates the Solar System. Because the Sun is essentially a ball of plasma – matter consisting of ionised gas – and not a solid, it rotates at different speeds depending on its latitude. This unequal rotation causes kinks and twists in the magnetic field, creating sunspots and solar flares, which are usually accompanied by the expulsion of energetic particles in the form of solar wind and coronal mass ejections (CMEs). These particles provide Earth with its aurorae as they collide with the Earth's upper atmosphere.



Observing the Sun in different wavelengths can reveal more about its surface and atmosphere



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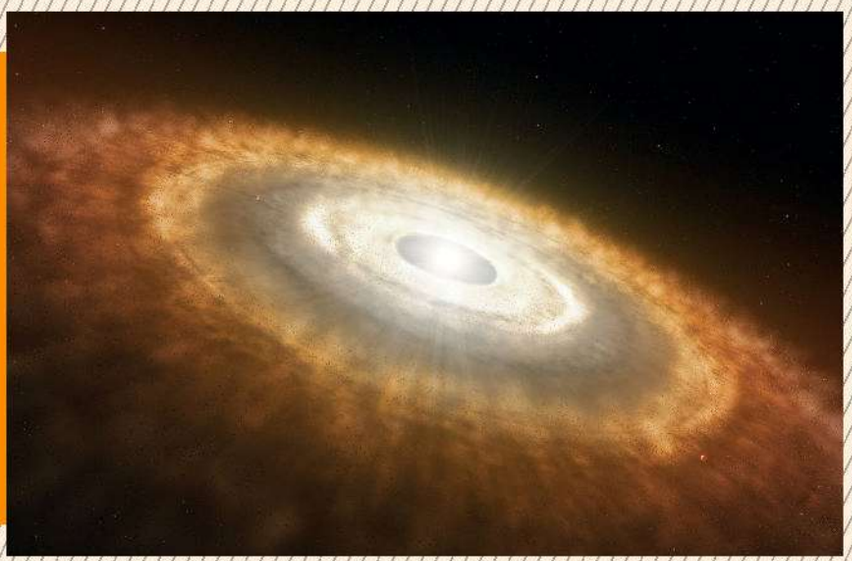
NEWS FROM THE SUN

Studying the solar wind

Scientific papers have been released based on the data collected by NASA's Parker Solar Probe (PSP). One of the new announcements shows the complexity of solar wind. On Earth it is seen as a constant flow of plasma, but the PSP has shown a more complex and active system. The PSP's FIELDS instrument has found sudden reversals in the magnetic field and incredibly fast jets of material occurring much closer to the Sun. Understanding this is key to understanding how the solar wind is moving away from the Sun and permeates the Solar System. "The complexity was mind-blowing when we first started looking at the data," says Stuart Bale of the University of California, Berkeley, lead for the PSP's FIELDS instrument suite.

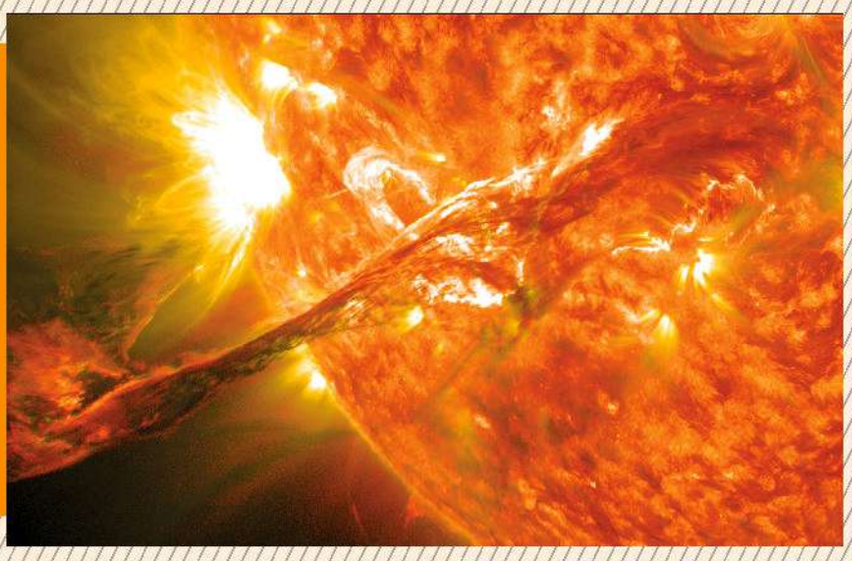
What's happening to the dust?

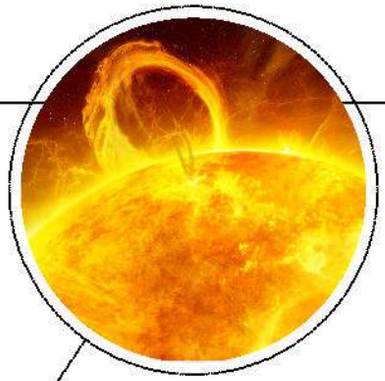
Dust is everywhere in space. However, there is a dust-free zone close to the Sun, and it's thought the temperatures up close obliterate it – but this has never been proven. Now the PSP has shown evidence that this is the case. Its Wide-field Imager for Solar Probe (WISPR) has observed dust thinning at a distance of just over 11 million kilometres (7 million miles) from the Sun. The thinning effect continued to be observed as close as 6.4 million kilometres (4 million miles). "This dust-free zone was predicted decades ago, but has never been seen before," says Russ Howard, principal investigator for the WISPR suite at the Naval Research Laboratory in Washington, DC. "We are now seeing what's happening to the dust near the Sun."



Detecting solar flares in real time

Scientists at the Cooperative Institute for Research in Environmental Sciences (CIRES) and the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information have developed a machine-learning technique to highlight significant changes in space weather. "Being able to process solar data in real time is important because flares erupting on the Sun impact Earth over the course of minutes. These techniques provide a rapid, continuously updated overview of solar features and can point us to areas requiring more scrutiny," says Rob Steenburgh, a forecaster at the NOAA Space Weather Prediction Center in Boulder, Colorado.





HONOURABLE MENTIONS FOR SOLAR EXPLORERS

- **Mission:** Helios
  Operator: NASA/German Aerospace Center (DLR)
  Active years: 1974 to 1986
- **Mission:** Ulysses
  Operator: NASA/ESA
  Active years: 1990 to 2009
- **Mission:** Solar and Heliospheric Observatory (SOHO)
  Operator: NASA/ESA
  Active years: 1995 to present
- **Mission:** Genesis
  Operator: NASA
  Active years: 2001 to 2004
- **Mission:** Deep Space Climate Observatory (DSCOVR)
  Operator: NASA/NOAA
  Active years: 2015 to present
- **Mission:** Parker Solar Probe
  Operator: NASA
  Active years: 2018 to present
- **Mission:** Solar Orbiter
  Operator: ESA
  Active years: 2020 to present

"The coldest layer of the Sun is the photosphere – the visible surface"

SUN FACTS

Sunspots are darker, cooler spots that appear on the Sun's photosphere that arise from complications within the star's magnetic field

1.3 million Earths could sit within the Sun, or around 1,000 Jupiters

At the equator of the Sun, it takes **25 days** to complete one full rotation, but regions towards the poles take closer to **36 days**

The shape of the Sun relies upon hydrostatic equilibrium, which means the pressure of gravity is equal to radiation output

The Sun contains traces of heavier elements such as **oxygen, carbon, neon** and **iron**

An astronomical unit (AU) is the distance between the Sun and Earth and is used to describe distances in the Solar System

THE PAST, PRESENT AND FUTURE OF SOLAR EXPLORATION

There have been many satellites launched to investigate the Sun's activity, the first dating back to 1960 with NASA's Pioneer 5 spacecraft. Since then, instruments, engineering and our understanding of the solar environment have drastically improved. A few missions that have shaped understanding include NASA and the European Space Agency's (ESA) Solar and Heliospheric Observatory (SOHO), NASA's Solar Dynamics Observatory (SDO) and the Japan Aerospace Exploration Agency (JAXA) mission – with collaboration from NASA and the United Kingdom – called Hinode.

On 12 August 2018, NASA launched its Parker Solar Probe (PSP), breaking boundaries when it comes to scrutinising the Sun. At its closest approach the PSP will travel within the Sun's atmosphere at a distance of 3.8 million miles. This mission carries with it four specially designed instrumental suites that look to answer questions about the corona and solar wind while experiencing temperatures of roughly 1,377 degrees Celsius (2,500 degrees Fahrenheit).

In 2020, the ESA launched its Solar Orbiter to get close to the Sun (but not as close as the PSP) at a distance of 41.8 million kilometres (26 million miles). The main difference is that the Solar Orbiter will utilise the gravity of Venus to swing it into a greater inclination, potentially as high as 33 degrees. This will allow it to probe the poles of the Sun, a feat that has never before been accomplished by any other spacecraft.

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FOCUS ON

SCIENTISTS GET A GRUESOME LOOK AT HOW OUR SUN WILL EAT PLANETS

Peering into our Solar System's future

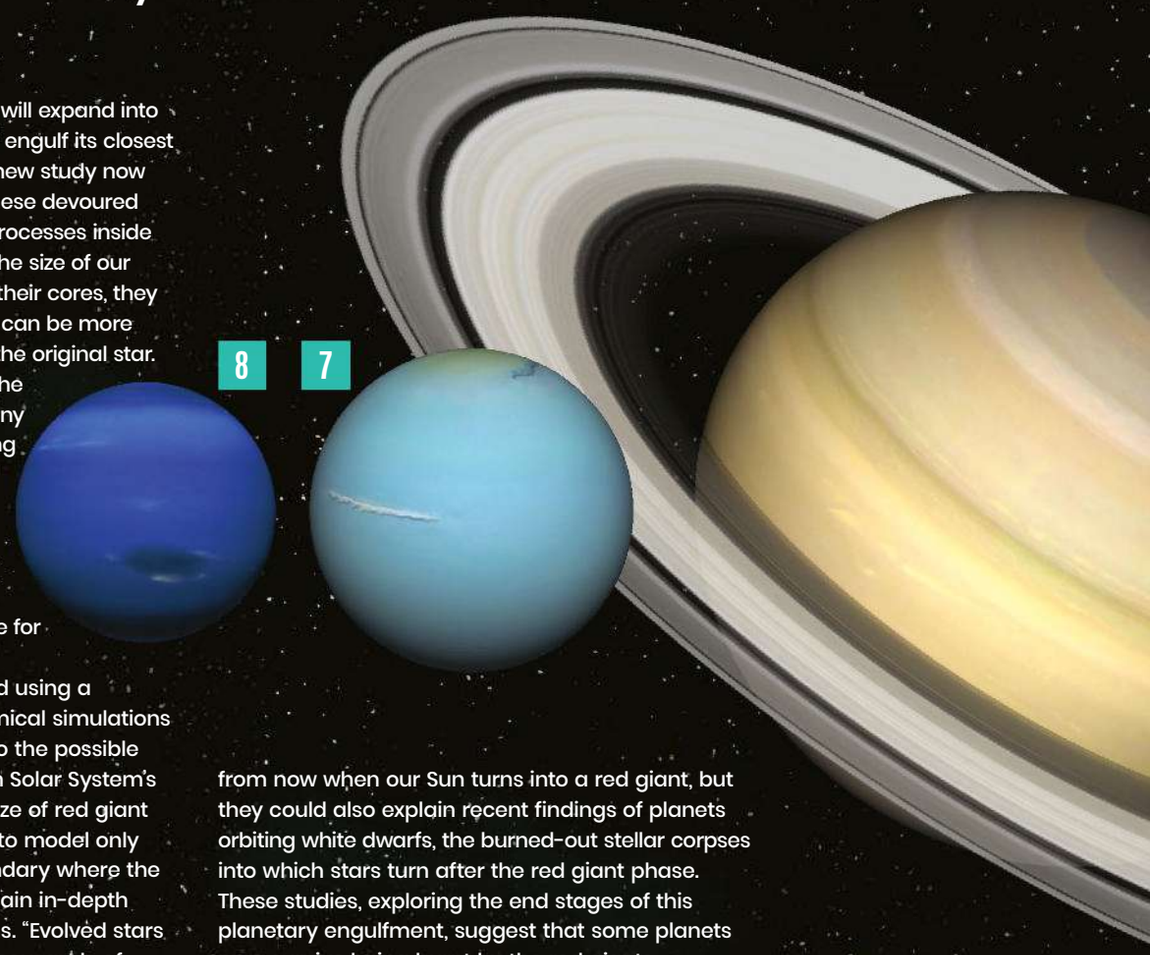
Reported by Tereza Pultarova

One day our Sun will expand into a red giant and engulf its closest planets, and a new study now explores how these devoured planets can influence the processes inside the dying star. When stars the size of our Sun run out of hydrogen in their cores, they balloon into red giants that can be more than ten times larger than the original star. As these red giants engulf the planets that orbit them, many things can happen. Engulfing large planets, ten or more times the size of Jupiter, can trigger the star into shedding its envelope and increasing its brightness by several orders of magnitude for several thousands of years.

The study was conducted using a method called hydrodynamical simulations and provides a glimpse into the possible future scenarios of our own Solar System's evolution. Because of the size of red giant stars, the researchers had to model only a small section of the boundary where the stars meet the planets to gain in-depth insights into the interactions. "Evolved stars can be hundreds or even thousands of times larger than their planets, and this disparity of scales makes it difficult to perform simulations that accurately model the physical processes occurring at each scale," said Ricardo Yarza, a graduate astronomy student at the University of California, Santa Cruz, and lead scientist of the study. "Instead, we simulate a small section of the star centred on the planet to understand the flow around the planet and measure the drag forces acting on it."

Not only could the results provide a glimpse into what will happen 5 billion years from now when our Sun turns into a red giant, but they could also explain recent findings of planets orbiting white dwarfs, the burned-out stellar corpses into which stars turn after the red giant phase. These studies, exploring the end stages of this planetary engulfment, suggest that some planets may survive being burnt by the red giants.

In our Solar System, the closest planets to the Sun – Mercury and Venus – are expected to get swallowed by the growing Sun entirely. Earth, while it may survive, will be so scorched that it will become completely uninhabitable. Some of the more distant and currently freezing cold bodies, such as Jupiter, Saturn and their moons, may develop more life-friendly conditions in the vicinity of the blown-up Sun. While only a few planets that have likely survived a red giant engulfment have been observed so far, researchers believe that further studies of exoplanets will lead to more such discoveries.



Earth will be so scorched by the expanding Sun that it becomes uninhabitable

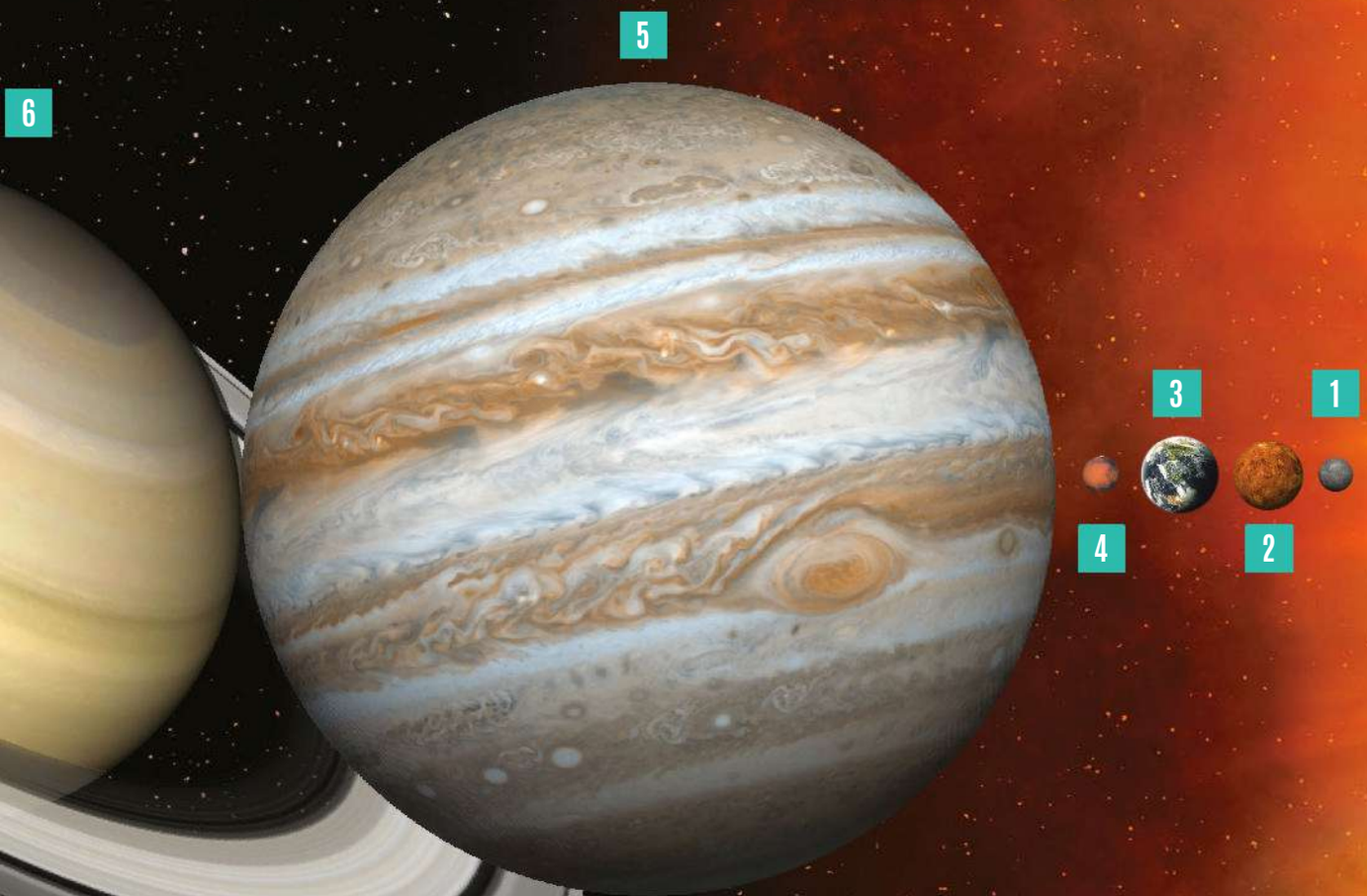
1 Mercury
If Mercury's orbit remains stable until the Sun's red giant phase, the innermost planet is sure to be swallowed up by the expanding star.

2 Venus
The Sun's increasing brightness will blast away Venus' present-day thick atmosphere before swallowing up the planet itself.

3 Earth
The Sun's loss of mass will send Earth's orbit spiralling outwards, but then tidal effects will draw it back, ensuring that our planet, too, is burnt to a cinder in the Sun's outer layers.

4 Mars
Our outer neighbour will probably survive the Sun's expansion and could even have habitable conditions for 100 million years or so.

5 Jupiter
Increased solar heating will cause Jupiter's atmosphere to balloon in size. Its giant moons will enjoy a habitable phase lasting around 30 million years.



6 Saturn
Saturn's atmosphere will also expand, and its rings will likely be long gone. Its moons, including the giant Titan, may benefit from 8 million years at habitable temperatures.

7 Uranus
The inner of the Solar System's two ice giants, Uranus will experience habitable temperatures, warm enough to melt ice on the surface of its moons, for just 2 million years.

8 Neptune
The outermost of the major planets, Neptune orbits so far from the Sun that it will never make it out of deep-freeze, even when the Sun is at its biggest and brightest.

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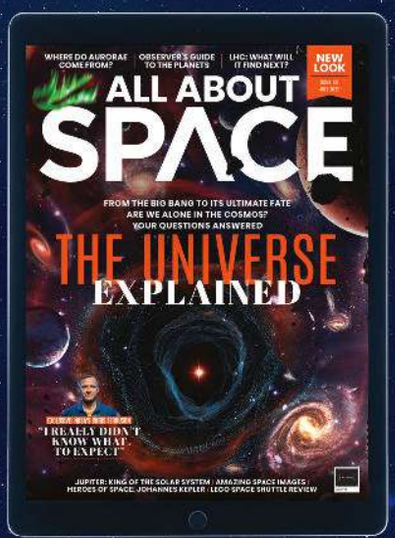

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INSTANT EXPERT

WHAT ARE PLANETS LIKE ON THE INSIDE?

Even among the worlds of our Solar System we see a huge variety of planets

The terrestrial planets – Mercury, Venus, Earth and Mars – are separated into similar layers: a hot dense core, a warm pliable mantle and a cooled rocky crust. Mercury is around 70 per cent metallic and 30 per cent rocky. Its core is thought to comprise as much as 85 per cent of the planet, a liquid heart of iron 4,000 kilometres (2,485 miles) in diameter. This is covered by 600 kilometres (373 miles) of silicon-rich mantle and between 100 and 200 kilometres (62 and 124 miles) of rocky crust. Venus was expected to have a similar structure to Earth, but Venus has little magnetic field. Earth's field is created by rotation and convection in our molten core; Venus does seem to have a molten core, but for some reason it doesn't circulate in the same way. One possibility is that Venus' crust doesn't get recycled like Earth's does, so the whole core may be of uniform temperature as heat is not escaping to the surface.

Fortunately for us, Earth has a significant magnetic field that protects us from solar radiation, but our core isn't just liquid. The pressure at the centre of Earth is sufficient enough that the iron collected there becomes solid, despite the temperature being around 6,000 degrees Celsius (10,832 degrees Fahrenheit). This has been determined by studying the way seismic waves travel through Earth. The solid inner core is around 1,220 kilometres (760 miles) in diameter. This is surrounded by a liquid layer that is 2,200 kilometres (1,367 miles) deep, which is then topped by 2,900 kilometres (1,802 miles) of mantle and an average crust of 35 kilometres (22 miles).

Mars is also differentiated into layers, with a liquid core, a mantle – which appears to have driven volcanoes in the past – and a rocky crust. Like Venus, there must not be convection in the core, as Mars has no magnetic field.

Jupiter is the first of the gaseous planets and the largest in the Solar System. When it comes to gas giants, there's no sharp dividing line between the planet and its atmosphere. It's thought that Jupiter has a dense core, possibly rocky, surrounded by 'metallic' hydrogen. This is a strange condition predicted to occur under huge pressures, where hydrogen behaves like a dense electrically conductive substance. This layer is thought to cover 78 per cent of the thickness of the planet. It's thought that above this, normal liquid hydrogen smoothly fades into the gaseous hydrogen atmosphere. Saturn is thought to be similar to Jupiter, with a rocky or icy core surrounded by the same types of hydrogen layers.

Uranus and Neptune are called the ice giants, not because they have ice in the sense we know, but because a layer of mixed methane, water and ammonia surrounds their rocky cores – equivalent to the mantle in terrestrial planets. These molecules are referred to as ices, though they form a hot, dense liquid near the core and fade out into the atmosphere without a defined surface.

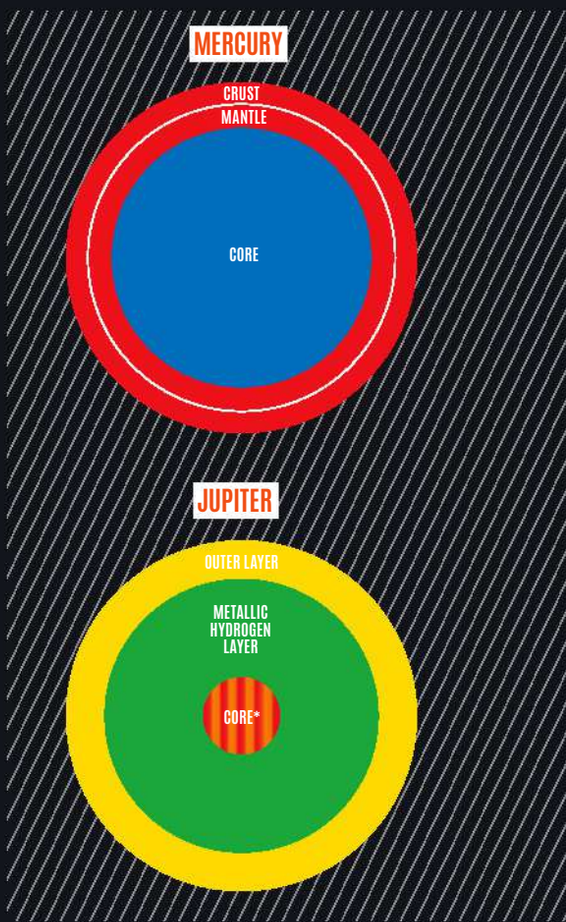
BIO

ROBIN HAGUE

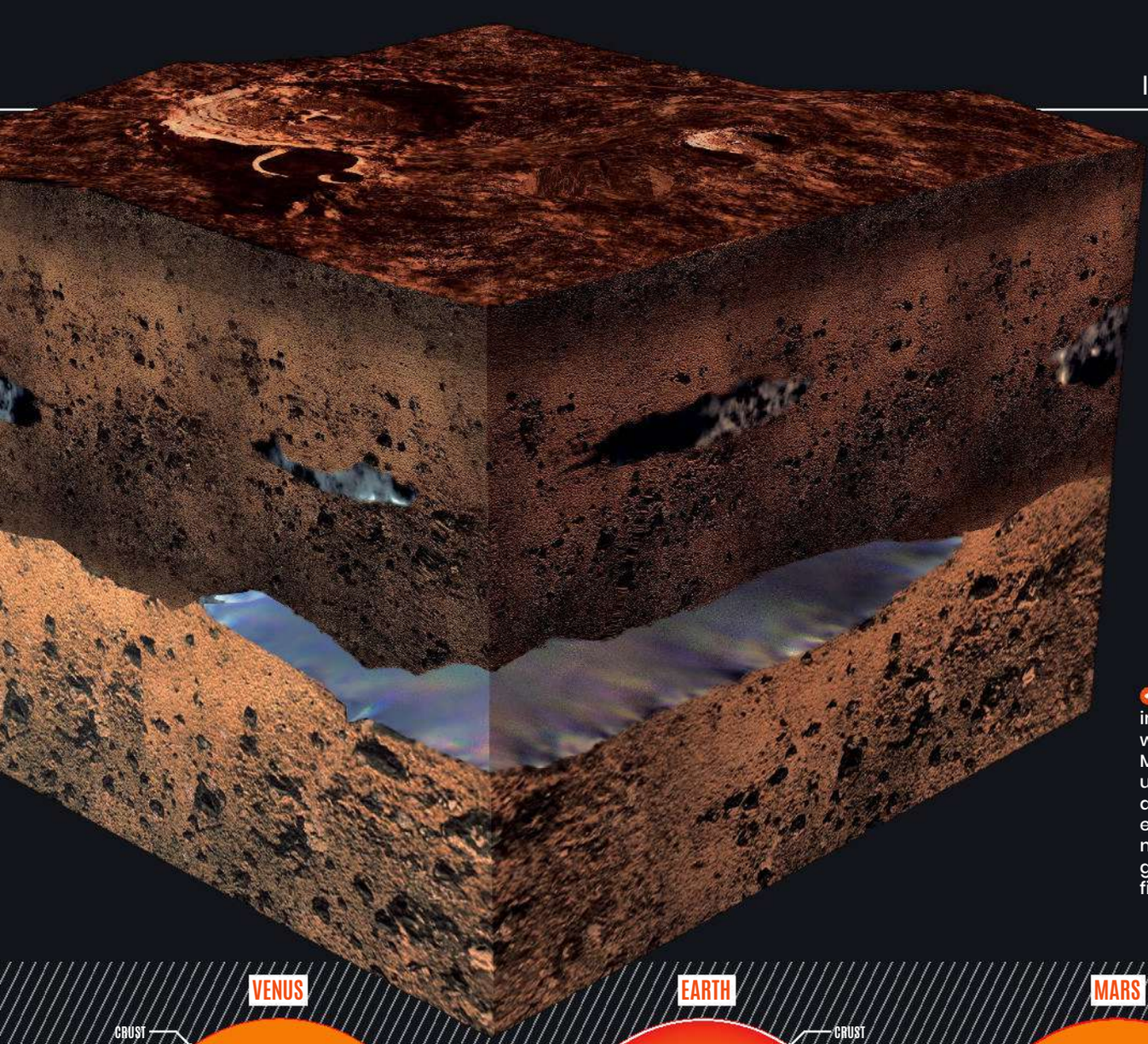
Robin is a science writer, focusing on space and physics. He is the current head of launch at Skyrora, coordinating launch opportunities for Skyrora's vehicles and liaising with UK launch regulators.

UNDER THE SURFACE

- ROCK
- MOLTEN ROCK
- ICE
- MOLTEN IRON
- IRON
- LIQUID METALLIC HYDROGEN
- HYDROGEN GAS
- ATMOSPHERE

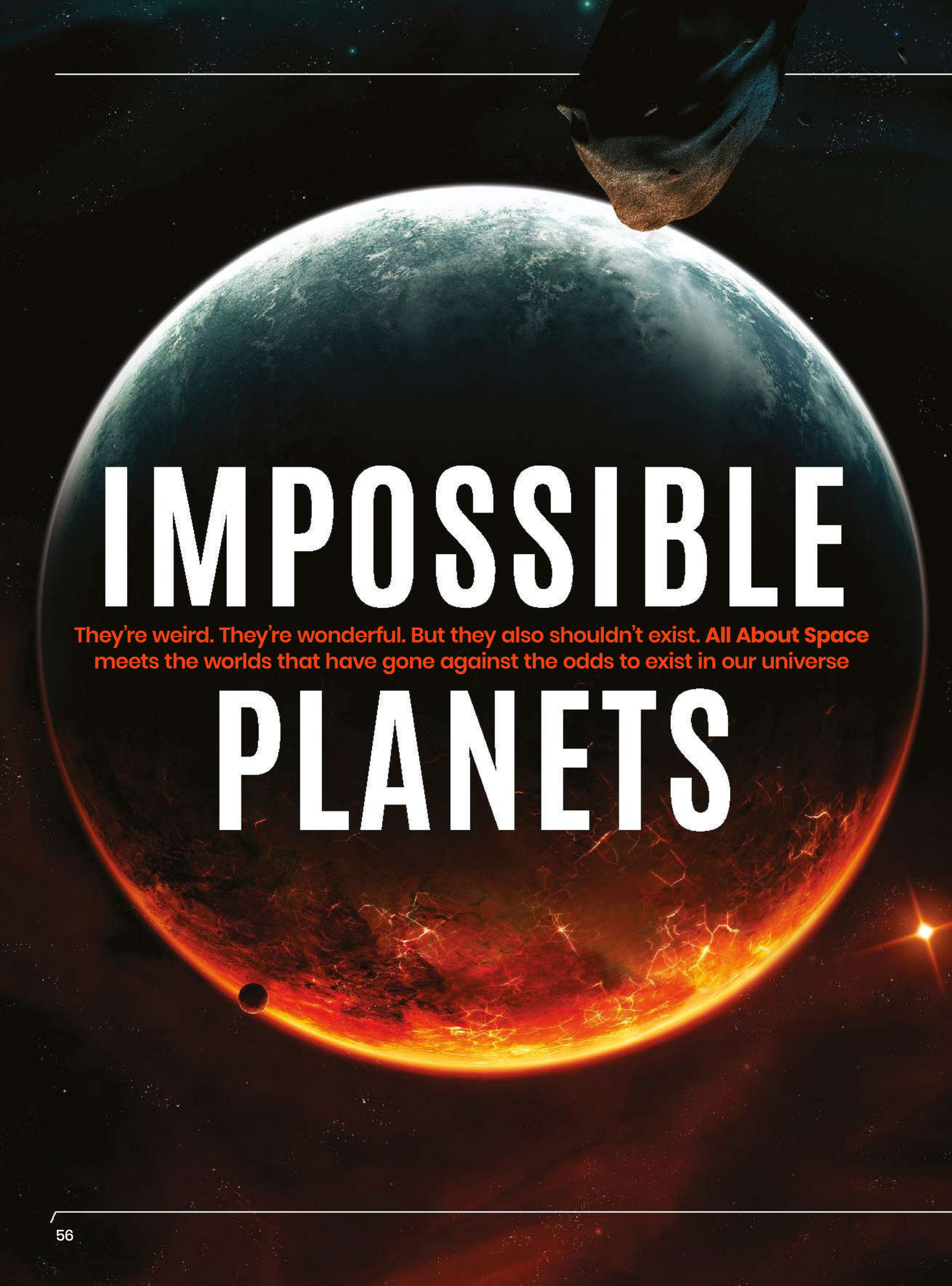


*JUPITER'S CORE REMAINS A MYSTERY TO SCIENTISTS, BUT IT'S HOPED THAT THE JUNO MISSION WILL SHED LIGHT ON ITS SIZE AND COMPOSITION



An artist's impression of water under the Martian surface. If underground aquifers like this exist, the many Mars missions have a good chance of finding them

© ESA



IMPOSSIBLE PLANETS

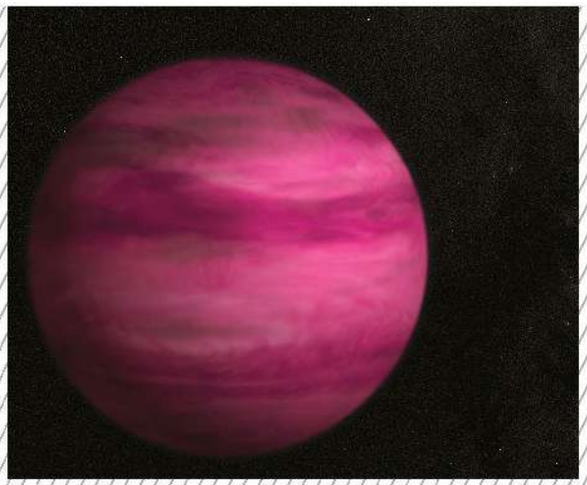
They're weird. They're wonderful. But they also shouldn't exist. All About Space meets the worlds that have gone against the odds to exist in our universe

Our Solar System is the model of how planetary systems should be: Earth at a comfortable distance from the searing heat of the Sun, inner planets braving the unbearable temperatures closer in on their orbits, while the bigger gas giants hang back, past an asteroid belt in the comparatively cooler part of the solar neighbourhood. While the eight worlds that orbit a star abundant in nourishing elements offer a wide range of extremes, we consider the beginning and end point of our place in the Milky Way galaxy as exactly how planetary formation and survival should be played out.

Our Solar System began with the makings of our very own Sun; starting its life from the almighty collapse of a small part of a giant molecular cloud – a stellar nursery of gas and dust. As our star began to spark into existence, thanks to a concoction of extra mass and high temperatures that set off nuclear reactions, leftover debris began to cluster around the young star, rotating as a spinning disc around a dense core. Then along came the planets, built like houses in a construction yard, as dust particles clumped together to form clusters which, in turn, led to boulders eventually becoming forced together by gravity to create the inner planets, their moons and other small Solar System bodies. Further out, temperatures were much cooler, allowing volatile ices – which were easier to find than the metals and silicates that made the inner planets – to remain rock hard. What happened next took several millions of years as the gas giants used their icy cores to their advantage, grabbing as much hydrogen and helium as possible to build their swollen limbs. The asteroid belt, which we find resting between the orbits of Jupiter and Mars, was once a playing field for Moon to Mars-sized planetary embryos. However, lying so close to the great gas giant which formed some 3 million years after the Sun, they were repeatedly smashed into each other and, with the added influence of Saturn, the broken pieces of what could have made up to three Earth-sized planets were left in disarray, forbidden to form anything but irregularly shaped asteroids.

But there are always exceptions to the rule. And, as we poke around into the deepest recesses of space using our wonderful technology – which includes

THE PINK WORLD
GJ 504 B



GJ 504 b is a recently announced Jovian planet that rests around 57 light years away from Earth around the yellow dwarf star 59 Virginis. It was picked up by the 8.2-metre Hawaiian Subaru Telescope that operates in the infrared wavebands. At around four times the mass of Jupiter yet similar in size, this distant world – which astronomers believe is coloured in magenta – is the smallest as well as one of the most ancient worlds that we've directly imaged, at around 160 million years old. You might think that the strangest thing about this planet is that it's the only pink world that we know of – but there's more to it than that – causing astronomers to place it up there as one of those weird worlds that they're having their work cut out in understanding.

Resting around nine times the distance that Jupiter orbits from our Sun, GJ 504 b certainly poses a challenge for our ideas of how giant planets form. It has long since been thought that gaseous worlds begin their lives in gas-rich debris discs surrounding a young star. However, experts are the first to admit that this only really holds true for planets as far out as blue planet Neptune, leaving us with no option but to give our theories some tweaking.

LIKE EARTH, BUT HOTTER
KEPLER-78B

At 1.2 times bigger than Earth and 1.8 times heavier with an almost identical density to our planet, Kepler-78b is similar to Earth – especially since it is likely to have been built from rock and iron. However, at 2,000 degrees Celsius (3,600 degrees Fahrenheit) that's where the similarities end. You'd be hard pushed to find life as we know it on its surface, in fact this world shouldn't really exist at all.

Circling its Sun-like star at around 40 times closer than Mercury orbits our Sun, Kepler-78b completes a year in only 8.5 hours and – according to how astronomers have visualised its surface – is a hellish molten world. As we currently understand it, our models of planet formation argue that this scorching lava world could never have formed so close to its star and it certainly could never have moved there. What's more, the fact that it continues to orbit its star without succumbing to gravitational tides is causing astronomers to wonder if they have chanced upon a new class of planet.

© NASA

the likes of the space-based planet hunter the Kepler Space Telescope, as well as the robotic observatories that comprise SuperWASP on the soils of La Palma and South Africa – we begin to find ourselves confronted with more than one planetary candidate that forms and survives just fine by bucking the trend in the most impossible way imaginable.

Using the transit method, which watches for dips in a star's light as the planet moves across its face to snare a world, as well as the radial velocity method, which finds planets thanks to their tell-tale gravitational tug on their star and causes a slight change in their parent's speed, we're finding exoplanets all the time. What's more, our observations are turning up more of the extreme worlds, forcing us to think of new ways how they may have come to form.

While we believed that there must be planets outside of our Solar System somewhere, no one was ready for the data turned up by astronomers Aleksander Wolszczan and Dale Frail in 1992 – a multi-planetary system around millisecond pulsar

THE PULSAR PLANET

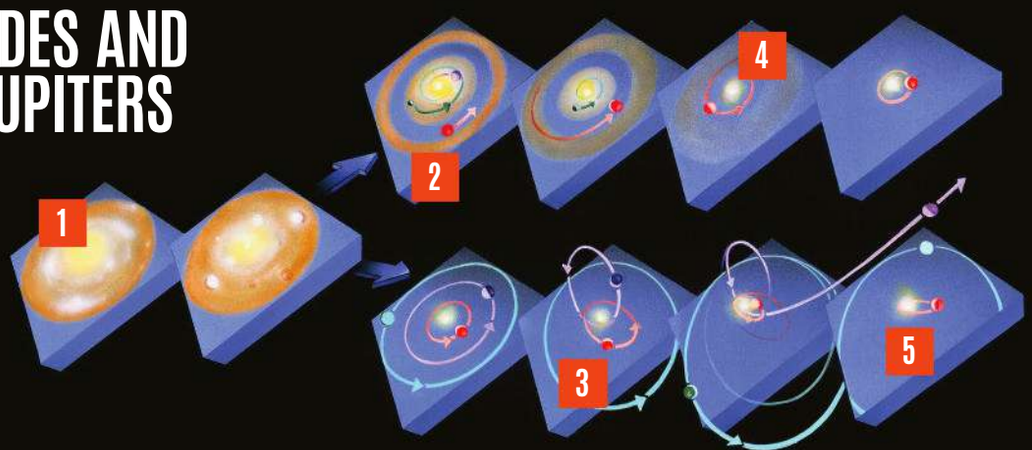
PSR B1257+12 B

The first ever exoplanet outside of our Solar System to be uncovered by Dale Frail and Aleksander Wolszczan in 1992 completely turned our ideas of how planets are made on their head. This is because it was found around a dead, radio and X-ray jet-beaming pulsar; these are essentially the corpses of massive stars that have endured the almighty explosion of a supernova. Frail and Wolszczan used pulsar timing measurements to look for irregularities in its otherwise regular pulsations and they struck lucky, uncovering two planets – one over three times the mass of Earth and the other just over four.

In a supernova explosion, the star is obliterated, leaving behind a tiny dense core that becomes the pulsar. The shock waves that erupt in this event's wake would destroy any orbiting planets. So how were planets able to still exist around the pulsar after such a violent event? One suggestion is that the gas and dust set to make the planet arrived at the end of the star's life, blown off the star in outbursts, or possibly part of the debris from the explosion.

TIDAL PARADES AND JUMPING JUPITERS

The universe has its fair share of planets that don't quite match up with our current ideas of how they form and evolve to their strange states. But that hasn't put astronomers off from trying to figure out some of these wildcards – especially if they have unusually tight or far out orbits. Two of the methods used by scientists are the 'tidal parade' and 'jumping Jupiter' theories, which split from a common evolutionary beginning and is explained here.



1 In the beginning
A planetary system is cobbled together from the construction yard that is a swirling disc of dust around its preformed star.

2 Planet death
Three planets are formed, but a larger world attempts to slow down its inner companions until they're shoved into their parent star.

3 Throwing out planets
The intense gravitational interactions between the worlds in this planetary system cause a planet to be thrown out.

4 On the edge
Slowed by dust, the large planet has the system to itself but begins to fall in. Thanks to the dust dissipating, it teeters near its star in a close orbit.

5 Remaining survivors
Once the world is thrown out, the surviving planets are forced into highly eccentric orbits.

© NASA/ESA; ESO; Science Photo Library

FROM ANOTHER GALAXY
HIP 13044 B

HIP 13044 b is a Jupiter-like extrasolar planet that orbits its ancient red star at a distance of around 2,300 light years away from Earth. It might rest in our Milky Way galaxy today but just what happened that caused it to end up there makes this planet a very strange beast indeed.

Astronomers think that HIP 13044 b came from outside our galaxy, from a stream of stars of an ancient satellite galaxy that our Milky Way started to rip into, cannibalising it and pulling HIP 13044 and its planetary companion into the fray between 6 and 9 billion years ago. This might seem like a logical explanation – HIP 13044 b just swapped galaxies and it has a very irregular orbit to show for it – but on closer inspection, astronomers are not quite happy with this theory.

Their main issue is with the exoplanet's star itself. Red stars mean old stars and this in turn suggests metal-poor. This implies that anything heavier than hydrogen and helium, including oxygen and nitrogen, which are needed to make planets, would be lacking. The rocky cores that we believe exist at the centres of gas giants would never be able to form, and there would be nothing for the planet's gaseous envelope to grab on to. That's why, during the early universe where everything was made of hydrogen and helium – including the first stars – there were never any planets being made. There just weren't enough 'metals'.

Just like Jupiter

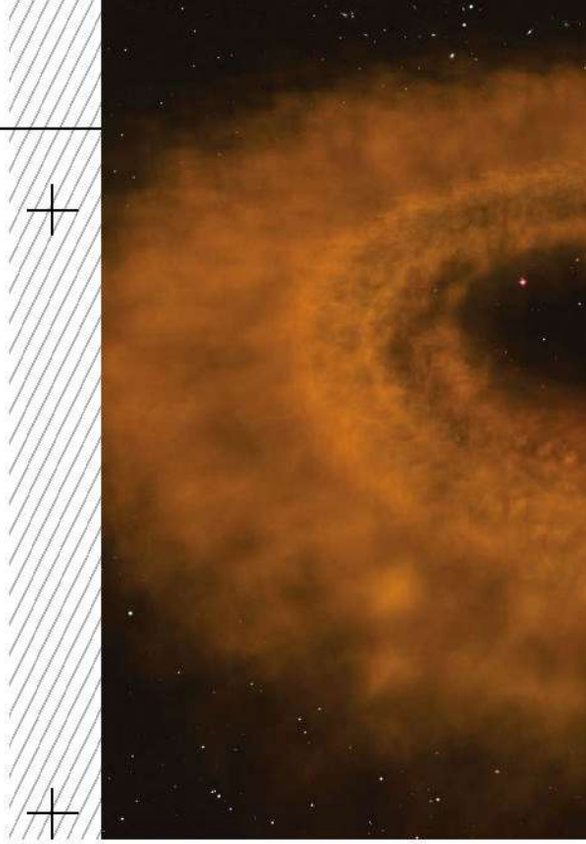
HIP 13044 b has a mass about 1.25 times that of our very own gas giant Jupiter. And, because it is so close to its star, its gases are heated to extremely high temperatures. This world is thought to have had other planetary companions, but they were most likely consumed by HIP 13044 as it evolved.

Ancient star

HIP 13044, which rests around 2,000 light years away from Earth, is an old and metal-poor star – stars that have a low amount of elements other than hydrogen and helium. It weighs in at 0.8 times the mass of the Sun with an age estimated at around 9 billion years old – at most.

Torn from its parent galaxy 6 to 9 billion years ago, HIP 13044 b underwent trauma when its star swelled into a red giant. The planet survived at the cost of an irregular orbit it completes every 16.2 days

PSR 1257+12. Highly magnetised, pulsars spin at eye-watering speeds throwing out beams of electromagnetic radiation and are the result of a catastrophic supernova explosion. It was a difficult concept for astronomers to get their heads around without pulling apart the theory of how our Solar System was made, our blueprint and the one and only way that we believed that planets could ever exist. While their appearance certainly baffled us, experts think that they might have found a theory around two decades after their discovery. It could be that these planets might have formed later on, built from material spat out by the exploding stars that later made the disc from which these pulsar planets rose. However, without being able to fully get into the thick of how these 'life after stellar death' worlds came about, astronomers are faced with just models – simulations that are failing to provide us with a clearer picture to keep our questions at bay. Indeed, a similar problem makes itself known if planets were ever to be confirmed around the pairing between white and red dwarf HU Aquarii, an eclipsing binary that rests some 570 light years away. Forming a cataclysmic variable that expels

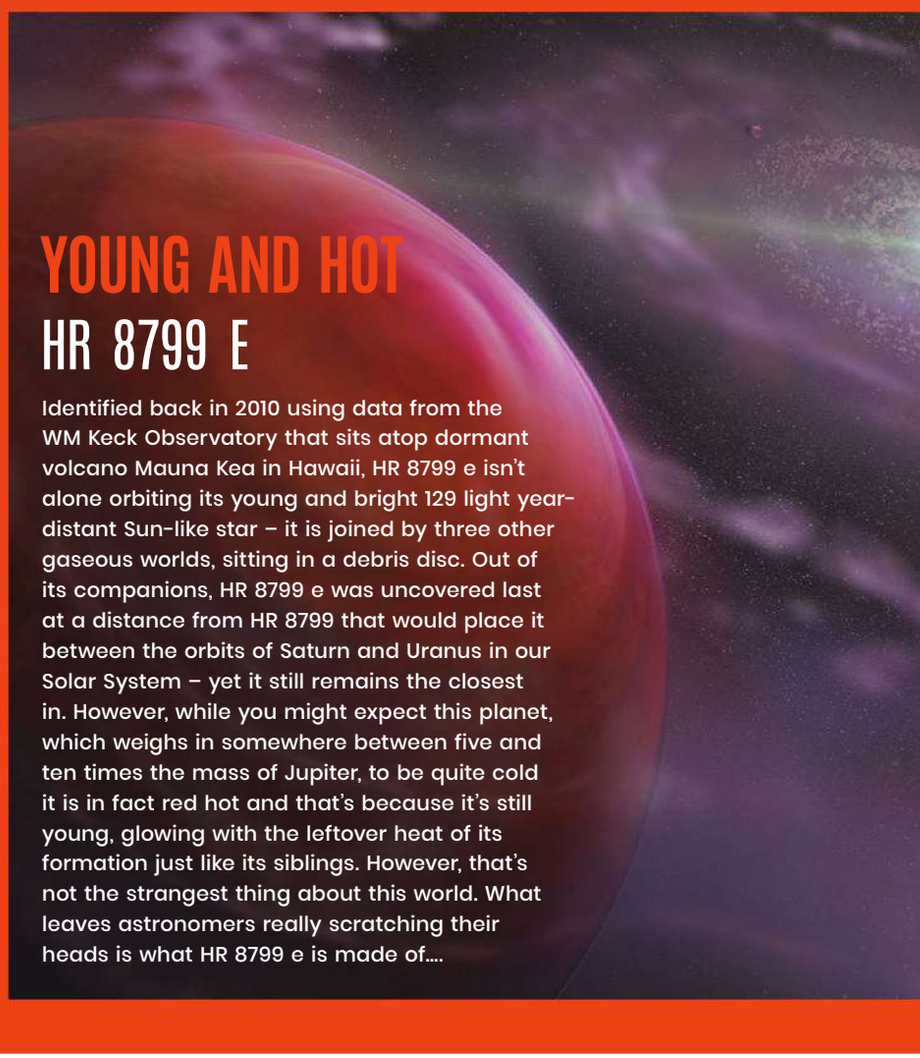


mass from the explosion of one star pulling material off its companion, it could be that a cloud of material that later became a disc ready to birth planets was blown into the system. But we're still not fully positive that this is the case.

Back in 1995, the appearance of more distant worlds continued to test our mettle, this time hitting closer to home as we chanced upon a world around a star not too dissimilar from our very own Sun. The first planet to ever be discovered around 51 Pegasi, resting some 50 light years away, completely blew our ideas of a universal planetary formation model out of the water. Swiss astronomers Michel Mayor and Didier Queloz had uncovered a world half the size of Jupiter and made of gas. At first thought, you might not think that there's too much of a problem – Jupiter and the other gas giants that follow it in our Solar System formed and still continue to orbit the Sun some 4.6 billion years later. But that's not the concern that astronomers had. It was the distance that this particular planet orbited from its star and, at less than 8 million kilometres (5 million miles) away, this world was not only closer in than the swift planet Mercury by around 50 million kilometres (31 million miles), it was also a lot hotter and made of a material other than the solid, resistant rock that we're used to when it comes to inner planets. We were faced with a world that didn't quite match up with how planets should exist and grow around stars like our Sun, a theory that we had been clutching tightly before this new discovery was made. Thrown by something so unreal, astronomers initially believed that 51 Pegasi b shouldn't exist but then they began to have a change of heart. Today we know these swollen, highly temperate worlds, which can hit over 1,000 degrees Celsius (1,800 degrees Fahrenheit), to be hot Jupiters. And ever since the first of these worlds cropped up, we've been finding a whole deluge of them. As seen in the very first example, they prefer to hug their stars rather than hang back millions of kilometres in the manner of our cooler gas giants.

"There are still some planets that refuse to fit our current models"

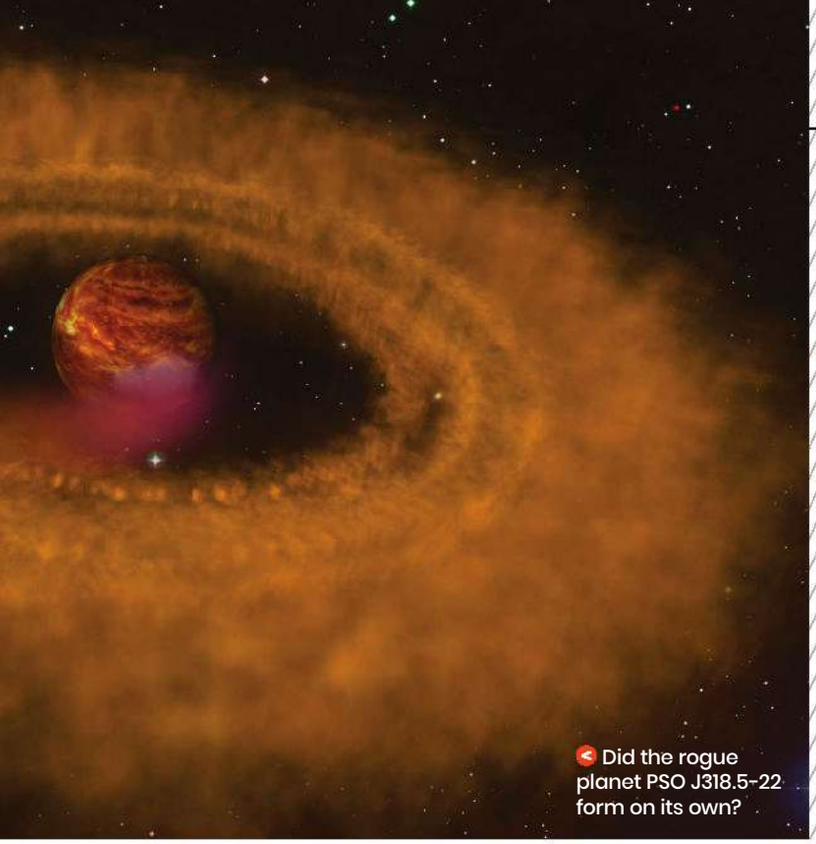
While the discovery of hot Jupiters has sprouted another branch in our knowledge, there are still some planets that refuse to fit our current models despite our best efforts of building on them all of the time. They exist and yet they shouldn't, that's as far as we know. And, with the advent of the next generation of bigger and better alien world hunters such as the James Webb Space Telescope – which was launched in December 2021 – we could find ourselves faced with two extremes: either we'll find solutions or receive further puzzles to solve if we discover even more wackier worlds to add to the mix.



YOUNG AND HOT

HR 8799 E

Identified back in 2010 using data from the WM Keck Observatory that sits atop dormant volcano Mauna Kea in Hawaii, HR 8799 e isn't alone orbiting its young and bright 129 light year-distant Sun-like star – it is joined by three other gaseous worlds, sitting in a debris disc. Out of its companions, HR 8799 e was uncovered last at a distance from HR 8799 that would place it between the orbits of Saturn and Uranus in our Solar System – yet it still remains the closest in. However, while you might expect this planet, which weighs in somewhere between five and ten times the mass of Jupiter, to be quite cold it is in fact red hot and that's because it's still young, glowing with the leftover heat of its formation just like its siblings. However, that's not the strangest thing about this world. What leaves astronomers really scratching their heads is what HR 8799 e is made of....



Did the rogue planet PSO J318.5-22 form on its own?

THE LONE PLANET

PSO J318.5-22

Confirmed by images taken with the Pan-STARRS 1 (PS1) wide-field telescope, PSO J318.5-22 is an exoplanet that prefers the single life. In short, it doesn't seem to be orbiting a star at all.

Experts have affectionately dubbed this gaseous world as a rogue planet. But, at approximately 80 light years away, this oddball isn't entirely a loner as it sits among the Beta Pictoris Moving Group – a gaggle of youthful stars. However, the fact that PSO J318.5-22 isn't dancing around any members in the group – which have been dated somewhere around 12 million years old – has thrown astronomers a bit of a curveball.

At 6.5 Jupiter masses, this world is too light to be a brown dwarf – the dividing line that separates planets and stars – so it must be a planet. Looking out into the universe, planets are usually found to orbit stars, whatever their type, so what happened to PSO J318.5-22? Could it have broken away from its star after being ejected or, even more oddly, formed alone?

The HR 8799 system as seen from one of its outer planets, HR 8799 c

1 Ten years later

Mapping out their orbits and predicting their motion, astronomers believe that they know where the worlds will end up over the next ten years.

2 HR 8799

The four planets orbit bright star HR 8799, which rests some 129 light years away from Earth. All worlds are roughly the same size, somewhere between five and ten times the mass of Jupiter.

3 Heavier than our Solar System

The HR 8799 planetary system – which includes HR 8799 b, HR 8799 c, HR 8799 d and HR 8799 e and their parent star itself – is thought to weigh in at around 20 times heavier than our Solar System.

4 Glowing brightly

Forming out of their debris disc these distant worlds are still hot, meaning that they are best viewed in the infrared wavebands.

© NASA; ESA;

FOCUS ON

NEW MARS MAP REVEALS HISTORY OF THE RED PLANET

Mars used to be much wetter than scientists thought

Reported by Robert Lea

A new map of mineral deposits on Mars could not only change our understanding of past water distribution on the Red Planet, but also help create a map for future Mars exploration, including crewed missions. It's revealed an unexpected abundance of minerals created by the interaction of rock and water, with hundreds of thousands of formerly water-rich areas discovered in some of Mars' most ancient regions. The map could lead to a more detailed investigation of Martian geology, revealing what happened when Mars changed from a planet like Earth to the dry and arid world we see today and whether the planet was ever capable of supporting life.

"I think we have collectively oversimplified Mars," John Carter, assistant professor at Institut d'Astrophysique Spatiale and part of the team behind the map, said. "The evolution from lots of water to no water is not as clear cut as we thought; the water didn't just stop overnight." He also explained that Mars' complex geology may be more similar to that of our planet than previously thought. "We see a huge diversity of geological contexts, so no one process or simple timeline can explain the evolution of the mineralogy of Mars. If you exclude life processes on Earth, Mars exhibits a diversity of mineralogy in geological settings just as Earth does."

The map has been created using over a decade's worth of data collected by the Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) instrument on the European Space Agency's (ESA) Mars Express spacecraft and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument on NASA's Mars Reconnaissance Orbiter. Of

> **"I think we have collectively oversimplified Mars"**
> **John Carter**

Mars is a dry and desolate place now, but once had seas and lakes like Earth

particular interest on the map are traces of water-rich minerals and rocks that were changed into clays and salts through interactions with water in the Red Planet's distant past.

Different water-rich clays and minerals are created when water interacts with rocks in a variety of conditions. When small amounts of water interact with volcanic rock, clay minerals such as smectite and vermiculite form. These retain many of the same chemical elements – particularly iron and magnesium – as the volcanic rocks that birthed them. When large amounts of water interact with rocks, however, the clays that are formed are less like the progenitor rocks, as soluble elements are washed away, leaving aluminium-rich clays like kaolin in their wake.

Up to a decade ago, researchers were only aware of around 1,000 such clay-rich outcrops on Mars. This meant aqueous clays were considered geological oddities and suggested that there were limitations to how much water had been on Mars in the past and for how long it had been preserved. The new map shows that these minerals are more prevalent than scientists thought, indicating that water played a much bigger role in shaping the geology of Mars. "This work has now established that when you are studying the ancient terrains in detail, not seeing these minerals is actually an oddity," Carter added.

Not only do these results suggest that water was prevalent and important in shaping Mars, but that the formation of clays and salts on the Red Planet is more complicated than previously suspected. In the past scientists thought that just a few clay types were formed when Mars was in its wet period – estimated to have been as long as 4 billion years ago. When the water dried up, the planet transitioned to the dry and arid world we see today, and salts were left behind.

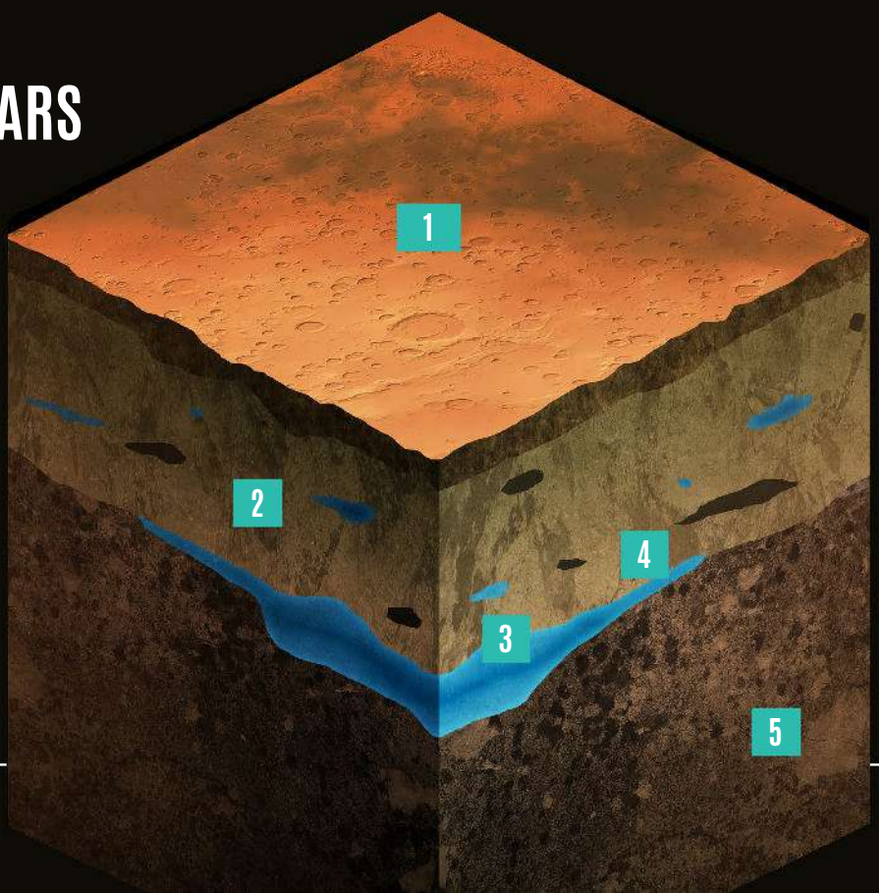
The new map shows that while salts did form after clays in many areas, in some locations across the surface there's a mixing of salts and clays, and there are also salts that predate the production of clay. The team behind the Mars mineral map didn't stop at the basic detection of minerals. They also quantified the concentrations of these aqueous minerals present in a variety of locations. Because these minerals still contain water molecules, they could be used by future crewed missions to extract water for both astronauts and for the production of fuel, lightening the load future space missions need to haul to the Red Planet as well as the cost of such missions. The clays and salts could even be utilised as building materials to establish bases and other facilities on the Martian surface. Even before crewed missions head to Mars, areas rich in aqueous minerals could prove excellent locations for robotic Mars missions to conduct geological research.

A prime example of this, Oxia Planum, a clay-rich site discovered during the creation of this map, has been suggested as a potential landing site for the ESA-operated Rosalind Franklin rover. "If we know where, and in which percentage each mineral is present, it gives us a better idea of how those minerals could have formed," Lucie Riu, an ESA research fellow, said. "This is what I am interested in, and I think this kind of mapping work will help open up those studies going forward."

WATER ON MARS

1 Dry soil
Martian soil forms a dusty layer, made up of nutrients such as sodium, potassium, chloride and magnesium.

2 Signs of ice
Surface ice is thought to have become buried, leaving a permafrost subsurface with young ice in its pores.



3 Pockets of water
Water ice is locked within cavities across the mid-latitudes of the planet.

4 Subsurface reservoirs
Underground lakes are thought to exist far beneath the surface of Mars, locked under land.

5 The foundation
Water would lie above an impermeable bedrock that has a high concentration of sulphur.

©Getty images

MYSTERIES OF THE UNIVERSE

WHAT CAUSES LIGHTNING SUPERBOLTS?

Superbolts have the potential to be very destructive, yet scientists still don't know why they pack more power than ordinary lightning

Reported by David Crookes

Lightning strikes are something to fear. Around 2,000 people are killed by them each year, and aside from causing many more injuries, lightning has the power to destroy objects too. But there's a type of lightning you wouldn't want to encounter. Called superbolts, they don't happen all that often, "yet they're 1,000 times more powerful than typical lightning," says Jean-Francois Ripoll, senior scientist at the Commissariat à l'Énergie Atomique (CEA) in Paris. "Superbolts are also potentially very destructive." But their cause and nature remain unknown decades after being discovered.

First reported in 1977, they were originally observed after the US Department of Defense developed Project Vela in 1963, a program that sought to find ways of monitoring nuclear explosions on or around Earth as the Cold War went on. By sending four satellites into orbit, the US was able to keep an eye on activity and ensure the Soviets were sticking to the 1963 Partial Test Ban Treaty. But the array of instruments on board those satellites, which included X-ray, neutron and gamma-ray detectors, also greatly aided science. Not only did Project Vela make one of the biggest space discoveries when it detected gamma-ray bursts, it also picked up on bright and energetic blasts. "They were genuinely brighter than most other lightning by

© GettY

definition, and that's how they became identified in 1977 from Vela satellite measurements," Ripoll explains. "The brightest events were so bright that their energy had to be far above the energy that was thought lightning could have."

From that moment on, scientists were unsure whether the observations actually pointed to a so-called superbolt. There was every chance these superbolts were simply normal lightning observed from a favourable satellite angle – that certain viewing conditions would affect their brightness and lead to an erroneous conclusion. But if they were real, scientists needed to find an explanation for how they formed.

"Lightning is a fascinating phenomenon, and here we are speaking of the rare events that are the most powerful, potentially the most dangerous ones," Ripoll says. Researchers have been able to confirm that superbolts do exist thanks to breakthroughs in recent studies. "But we still don't understand why they have become so powerful," he adds. Not only that, but scientists are still seeking to compute accurately what the energy of a superbolt is. "This is aggravated by the fact that superbolts behave in an opposite way to lightning, but it makes them fascinating," Ripoll says. "We just don't know why and what makes these superbolts happen and why they are so strong."

Satellite data shows superbolts tend to happen with far greater frequency in winter over the Mediterranean Sea, as well as off the tip of South Africa and east of Japan. "We don't know why, and that's a great part of the mystery," Ripoll says. "Most lightning occurs on land and in the summer, so superbolts behave in an opposite way." The only place where superbolts have been discovered over land is over the Andes Mountains.

Superbolts don't happen all that often. Satellite data revealed 600 million instances of ordinary lighting over the Americas between 2018 and 2020 – data that was recorded from the Geostationary Lightning Mapper mounted on the Geostationary Operational

SUPERBOLTS BY NUMBERS

1,000
times brighter than regular lightning

90+
Percentage of superbolt strikes over water

1.4 BILLION
Number of lightning flashes on Earth in a year

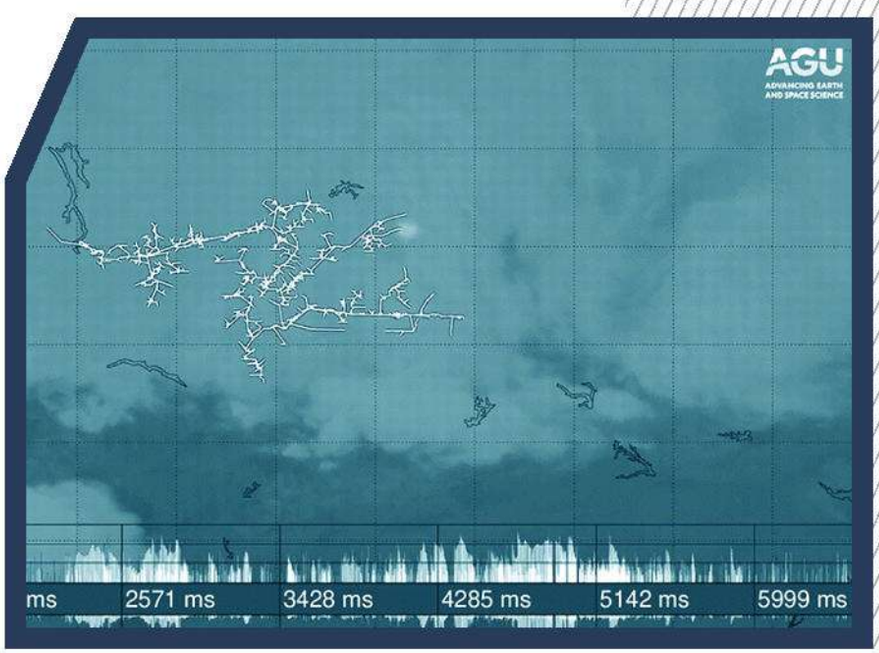
0.32
Percentage of superbolts compared to ordinary lightning

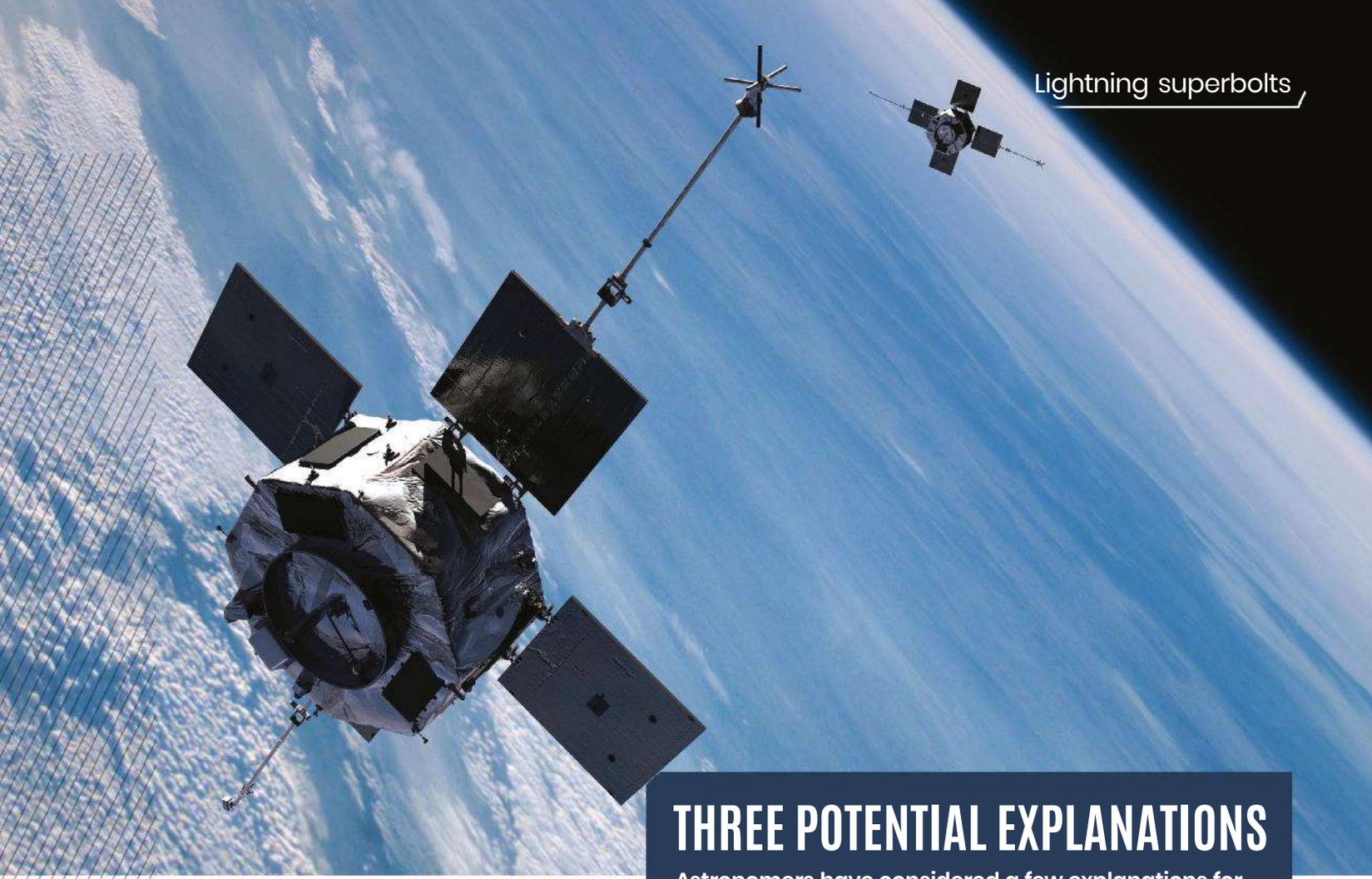
600
Number of superbolts on Earth between 2018 and 2020

FOUR
Months when most superbolts strike – between November and February

2013
Year most superbolts were recorded

100
Gigawatts of power produced by superbolts





Environmental Satellite-R Series – yet there were just 600 superbolts. Of every 10 million flashes of lightning, a superbolt only occurs five times or so. What's more, superbolts can be mistaken for massive nuclear explosions. Indeed, in 1979, many thought a two-pulse burst of light near South Africa had been a nuclear detonation, but since there was no detectable radiation from the light burst, scientists begged to differ. They concluded that the South African government hadn't developed a nuclear weapon, as had been feared, and that the incident was more likely one of those recently discovered superbolts. Still, even if that one was nuclear, it wouldn't have accounted for the rest.

"There have been many difficulties in bringing more and more phenomena together," Ripoll tells **All About Space**, before giving an insight into what is required in order to get to the bottom of the superbolt phenomenon. "Lightning involves fluid mechanics with radiative transfer, and you need to solve Maxwell's equations – or some form of them – to work out the discharge which forms the lightning," he says of the equations used in classical electrodynamics. "The discharge itself involves air chemistry, and that requires solving hundreds of partial differential equations as well. The modelling of a single lightning involves working out the radiative reacting plasma flow, which is highly challenging in terms of physics, maths and numerics. Lightning modelling and computation was a subject I was hired to work on at Los Alamos National Laboratory (LANL) between 2005 and 2007."

THREE POTENTIAL EXPLANATIONS

Astronomers have considered a few explanations for the origins of superbolts

Satellites have a good view

For a while scientists were unsure if the superbolts only flashed brightly because the observation tools on satellites were in a good position to be able to see them clearly.

They're affected by cosmic rays

Scientists are studying the possible relationship between superbolts and cosmic rays from stars exploding far away in the galaxy. More were spotted during the last solar maximum.

Water has an effect on them

The vast majority of superbolts occur over water during the winter months. They form when the clouds are positively rather than negatively charged. Could salt explain the brightness?

As Ripoll has said, superbolts are 1,000 times more powerful than the median energy of typical lightning on Earth. "This is a definition Robert Holzworth introduced in 2019 that myself and our team use as well," he explains of the findings by an experimental atmospheric and space physician based at the University of Washington. "In his case, we don't know the optical power – the amount of light that a lightning radiates per second. Instead we have its very low frequency (VLF) power – the electromagnetic power or energy per second. We can deduce the total lightning power from that, enabling us to compile statistics from lightning all over the world."

Electromagnetic observations of superbolts were obtained using data from NASA's Van Allen Probes, which orbited Earth to study the planet's radiation belts

Superbolt lightning can be seen over the southeastern US on 19 February 2019, as observed from the Geostationary Lightning Mapper

© Los Alamos National Laboratory; JHU/APL; NASA

And it's from this that we get an idea of just how powerful superbolts actually are. "When we compile statistics for all lightning hitting Earth, it turns out that the mean lightning energy is one kilojoule," Ripoll continues. "But we define superbolts – the most powerful of all lightning – as one megajoule. That's 1,000 times one kilojoule. What remains to prove is the unity of the two definitions so that we can prove the most powerful are the brightest. Physically speaking that should be correct, but it's unproven. So far we don't have simultaneous optical and electromagnetic measurements to prove that equation." This means scientists have been looking at the strength of a lightning flash as opposed to how much potential energy it contains. The two need to be brought together.

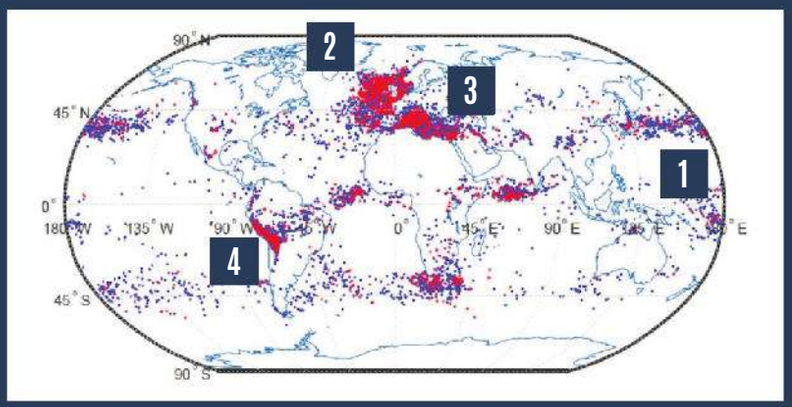
Ripoll's recent study examining the electromagnetic power of superbolts has greatly furthered scientific knowledge about them. "Our study has two main points," he tells us, the work having been published in *Nature Communications*. "The first is our ability to identify superbolts on Earth pretty well, either through measurements at the CEA or from the stations that make up the World Wide Lightning Location Network (WWLLN) run by Holzworth. We can then further see the superbolts propagating in space from orbiting satellites so that we can see what power is radiated away and where it's being radiated.

"The second point is that their power – their electromagnetic power on Earth – is also huge in space. We prove that the factor 1,000 that makes these events super powerful and rare on Earth is also conserved in space, where the power remains very large compared with typical lightning. This is important because we doubted the origins of some of the large electromagnetic waves we can measure in near-space when we don't have full temporal resolution of the measurements."

The study has enabled scientists to track a superbolt's electromagnetic power from ground to space over thousands of kilometres, he says, allowing the team to deduce many of their properties. "The measurements we used from NASA's Van Allen Probes are both at very high resolution and standard resolution," Ripoll continues. "The highest resolution ones were used to see the microstructure of the superbolts' electromagnetic signals and conclude that the standard measurements are not corrupted. The standard measurements don't show any fine structure that can tell the origin of the wave, so you can doubt the source is lightning." In short, they proved the huge electromagnetic signals in space, and thus superbolts, were real.

As it stands, however, it would appear this phenomenon exists only within Earth's atmosphere, albeit extended all the way into space. Superbolts certainly don't appear to happen on other planets in the Solar System, although there is a chance that under the same conditions they occur on some exoplanet somewhere out there in the night sky. "It applies to any discharge in a gas – not air necessarily – so you could imagine a planet with some atmosphere and some types of gaseous clouds that could charge," Ripoll says. "Then you could have a

The US generates 97.2 gigawatts of electricity every year from solar panels. A superbolt can produce at least 100 gigawatts of power



WHERE THE SUPERBOLTS ARE

Where do we see this supercharged lightning?

1 Find the superbolts
The dots on this map show superbolts between 2010 and 2018. The blue ones have an energy of more than a million joules.

2 Go extreme
There are also some super superbolts – those that have an energy in excess of 2 million joules are marked as red dots.

3 Locating the hotspots
You can clearly see where the hotspots are, with the majority in the North Atlantic and the Mediterranean Sea. There are other key spots east of Japan.

4 Sea and land
Although most of the superbolts strike over water, there is a large area of land struck by a relatively high number: the Andes Mountains in South America.

> **"The standard measurements don't show any fine structure that can tell the origin of the wave, so you can doubt the source is lightning" Jean-Francois Ripoll**

discharge between the gaseous clouds and the ground through the planet's atmosphere."

The task now is to learn more about the superbolts and their properties while figuring out why they occur at the times and places they've been observed. This requires taking simultaneous optical and electromagnetic measurements. "It will allow us to connect the electromagnetic power to the optical power in order to prove the most powerful lightning is the brightest," affirms Ripoll. There are numerous methods of doing this, with the French Space Agency's Tool for the Analysis of RAdiations from lightNIngs and Sprites (TARANIS) once being a great hope. "The TARANIS mission could have given us an answer, but it blew up in space when it was launched in November 2020," Ripoll laments. "There could have been some important outcomes."

Still, scientists continue their research. Ripoll says the hope is that the STPSat-6 satellite, funded by the US Department of Defense and launched in December 2021, will lead to a breakthrough. "LANL has put some dedicated electromagnetic and optical detectors on board," Ripoll says. "STPSat-6 may in turn bring some interesting answers, but the observations will be made from geostationary objects 36,000 kilometres (22,370 miles) away, which could be too far away and at frequencies that may not be optimal."

More generally, scientists need to continue observing lighting from space and from the ground and measure it the best they can. "There can be many important results of theoretical plasma physics in the atmosphere, ionosphere and magnetosphere that can come up from lightning physics, including ones applicable to subjects that have nothing to do with lightning. It's an important area of study and we are curious to see what new missions will bring."

It's a case of carrying on for scientists, especially given how close they're getting to solving this mystery. The many small satellites that are going to populate near-Earth space in the coming months and years will be instrumented, and they'll tell scientists more about atmospheric electricity while also helping to monitor global warming. "Maybe an increase in superbolt numbers can help us find a signature of global warming," Ripoll says. If so, there could be more of a kind of magic to these powerful phenomena than anyone had previously envisioned.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

A single lightning bolt captured by National Oceanic and Atmospheric Administration satellites across Texas, Louisiana and Mississippi in April 2020 had a vast distance of 768 kilometres (477 miles)

This megaflash – when lightning discharge is more than 100 kilometres (62 miles) across – is a world record for the longest lightning flash

© Jairo Valverde Bermudez; © Maps by FreeVectorMaps.com

SOLAR SYSTEM

How does organic material on Enceladus compare to that found on Mars?

The most intriguing difference is how easily you find complex organics on Saturn's moon Enceladus compared to Mars. If you consider the enormous efforts put into the search for organics on Mars since the 1970s without success, it's just amazing how easily we found complex and diverse organic chemistry on Enceladus with a spacecraft flying by. However, it's a huge success that NASA's Curiosity finally found organics on Mars. From what I read, the organics on Mars – like the Enceladean ones – could be large molecules that contain aromatic and aliphatic structures. Whereas we find oxygen and probably nitrogen in both organic molecules, the Mars organics do contain sulphur. The Cassini instruments were not very sensitive to sulphur, so it might be the case that it's there as well without us noticing it.

On Mars, over 50 space missions with several generations of rovers were required. On Enceladus it was just one exploratory spacecraft with instruments on board that were not even built to investigate Enceladus in the first place – keep in mind that Cassini and its instruments were built before scientists even knew about the activity on Enceladus. Just imagine what a much better job in looking for life we could do if we just spend a small fraction of the time and money that was spent for Mars to go back to Enceladus with instruments that are actually built to do that.

Frank Postberg, planetary sciences professor in the department of Earth sciences at Freie Universität Berlin

Did you know?

Enceladus is the sixth-largest Saturnian moon, with a diameter of 505 kilometres (314 miles).

Rare organic chemistry was detected erupting from Saturn's moon Enceladus by NASA's Cassini spacecraft

HUNT FOR LIFE

How common are planets that can support advanced technology like ours?

The Drake equation is one theoretical model for how common planets with intelligent life are. NASA is also working towards answering parts of this question. Scientists are studying the fraction of stars that have planets where water can exist as a liquid on the surface and the fraction of those planets that have Earth-like atmospheres. Only partial answers are available to these questions at this time. We are now certain that potentially habitable planets do exist around other stars, but they remain difficult to detect. Even for the nearest stars, we are not yet capable of detecting the habitable planets that may exist around them. And we still lack information as to whether they have Earth-like atmospheres. We are laying big plans to answer these questions by direct observations with future space telescopes – two such possibilities are the Habitable Exoplanet Observatory and the Large Ultraviolet Optical Infrared Surveyor.

Karl Stapelfeldt, chief scientist of the NASA Exoplanet Exploration Program

SPACE EXPLORATION

What is the future of space travel?

Low-Earth orbit, this tiny slither of space about 400 kilometres (250 miles) up, is no longer the purview of governments and large aerospace companies. New space companies are taking advantage of what we call the democratisation of space. Why is access to space becoming easier? In part it's because the cost to get to space is dropping significantly, and there are three main reasons for that. The first is reusability. Secondly there is also a rapid growth in production and deployment of very small spacecraft called CubeSats. The third reason is that we are developing much higher capability in much smaller packages – if time is money in business, then mass is money in the space business.

That is opening up the space environment, so the exploration of the past is being replaced by space commerce, at least at low-Earth orbit. There are private spaceports opening up all around the United States, and a few internationally. Spaceports embody space tourism, which is a world in which space becomes accessible to you and to me. When Virgin Galactic explore outer space and everything goes well, within about a year they will have flown three times as many people into space then have gone in the previous 60 years.

Private commercial enterprises taking over low-Earth orbit allows government-led enterprises, such as NASA and so on, to focus on creating the new phase of exploration. They take the next steps to push those frontiers much further.

David Alexander, director of Rice University's Space Institute

- We are currently aware of over 5,000 exoplanets
- Virgin Galactic's spaceport will send members of the public into space

© ESO, Virgin Galactic

MOONS

How did Titan get oceans of liquid methane?

Titan has methane because it's a relatively big moon that exists in the cold outer Solar System. Being big provides enough gravity to make it difficult for methane molecules to leak into space. Cold temperatures also inhibit escape by slowing molecules down. It turns out that Titan's surface temperatures – around -180 degrees Celsius or -290 degrees Fahrenheit – are just right for methane to liquefy.

The cold temperatures also serve another purpose – they keep water frozen at Titan's surface, preventing a large number of oxygen atoms from entering the atmosphere. If that were to occur, the carbon in Titan's methane would be combined with oxygen and Titan would have a carbon dioxide-rich atmosphere similar to those of the warmer inner planets Venus and Mars.

There might also be a vast subsurface reservoir of methane-rich ice that is tapped by cryovolcanoes, and this may have delivered fresh supplies of methane to the surface in the geologically recent past.

Dr Christopher Glein, senior research scientist at the Southwest Research Institute in San Antonio

SPACE EXPLORATION

How does a real-time rocket launch compare to simulations in training?

Our simulations didn't include any of the dynamics of the ride on the booster, but primarily trained us to recognise system problems with the boosters that might require an abort or takeover of control. At liftoff you could tell that you were moving, but it was not a 'big kick in the pants'.

The couches we laid in were suspended with some clearance provided on each side so they could stroke in the event of a hard landing from failed parachutes, or even to support an abort resulting in a landing on land. The highest g level was a bit over 4g – that was modest compared to our past career experience with combat manoeuvring in fighter aircraft. The biggest surprise to me was when the engines shut down ahead of staging. If I hadn't been strapped in, I would have been thrown into the instrument panel.

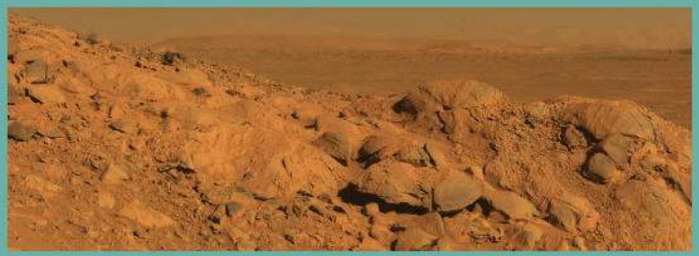
Fred Haise flew on board Apollo 13

HUNT FOR LIFE

Where's the most likely place to find life in the Solar System?

I think the best place for us to search is in the rocks of Mars that are protected from the ionising radiation currently bombarding the surface. Finding signatures of ancient extraterrestrial microbial life and establishing confidence in that finding will largely depend on the quality of the preserved record. Radiation can seriously alter ancient biosignature records – especially organics – but to what extent and how remains elusive. The reality is that any chemical and physical alteration can complicate and lower our confidence in interpreting signs of ancient life. The same is true for interpreting ancient terrestrial biosignatures. On Mars, I think it's fair to assume that if life ever existed there, it would be very adaptive. Over the aeons, life may have learned to cope or even utilise ionising radiation by moving to shielded environments, such as the subsurface, and evolving biochemistry to repair damage to cells.

Dr Jennifer Eigenbrode, interdisciplinary astrobiologist at NASA's Goddard Space Flight Center



Haise was launched into space on top of a Saturn V rocket

Many missions are looking for signs of past life on Mars

Astronauts must undergo a vigorous training regime before they can reach space

SPACE EXPLORATION

What are the fundamental characteristics needed for someone to become a successful astronaut?

Some of the simple things are an outrageously healthy body – because you have to be able to pass the hardest physical in the world to be deemed safe to send to the space station – and the second is a proven ability to learn complicated things. We tend to choose folks who have an advanced university degree, because if you have a PhD in polymer chemistry then you've shown you can learn complicated things.

The third is a proven ability to make good decisions when the irreversible consequences are high. So how do you choose someone who has shown that they're not only a healthy student, but also someone who can react appropriately and make good calls in a highly stressful, high-threat environment.

Then, to a large part, there's psychology: what type of person are they? Is this someone I'd want to fly in space with? Would I trust this person with my life? And would I want to be on board a spaceship for six months with them? That's the list of things we're looking for.

Chris Hadfield, Canadian astronaut who flew on two Space Shuttle missions and was also commander of the International Space Station

© NASA

15 TIPS YOU NEED TO BE A BETTER ASTRONOMER

From planning ahead to improving your observing skills, here's how to make your time outside with the night sky more efficient and enjoyable

Written by Jamie Carter

The universe is a big place. While you may have learned to navigate the night sky on a basic level, are you getting as much as you can from your observing? You may be a casual stargazer, or you may have more serious ambitions; either way there are some tried-and-tested ways of doing things better. Many things can determine when you should step outside, from the phase of the Moon to how well prepared you are. Are you dark-adapted? Are you dressed for the occasion? Are you looking at the star clusters and nebulae properly? From understanding your eyes to pushing yourself to learn more, these tips will help you improve your night under the stars and get better results. As always with stargazing and astronomy, there's always something new to learn.

CHECK THE MOON

1 Are you stargazing at the right time of the month? During full Moon our satellite rises at dusk and sets at dawn, effectively acting as a giant light polluter all night long. That makes the night of the full Moon the worst night of the month for stargazing and astronomy. The four or so days either side of full Moon also see a bright Moon dominating the night sky, blotting out stars and constellations. So when should you go stargazing? The darkest night of all is that of new Moon, exactly two weeks after and before full Moon. During that time the Moon is between the Earth and the Sun, so from Earth we can see none of the illuminated side of the Moon. However, for around four or so days before new Moon a waning Moon rises after midnight, and just after new Moon it's a slim waxing crescent that sets soon after dusk. So if you really want to plan the perfect night of stargazing, aim for new Moon week.

HAVE AN OBSERVING LIST

2 Stepping outside into the dark instantly knowing what stars and constellations are above you at that time of night, and that time of year, is one of the joys of long-term stargazing. However, you need to keep learning new things to keep things interesting. The easiest way is to get hold of a book of observing targets. Another way is to choose a constellation to explore in detail using binoculars or a telescope; or develop an interest in galaxies, nebula or star clusters and hunt for those.

CHOOSE A DARK-SKY SITE

3 Unless you live far enough from the nearest town or city, your stargazing will be affected by light pollution. That's not quite the disaster it may seem when you're starting out, because light pollution only allows the brightest stars to be visible. This can make it easier to get to know the night sky, allowing you to easily find constellations. However, if you go to a place with very little light pollution you'll be amazed by what else you can see.

GET UP HIGH

4 Elevation is everything. There are two reasons why getting yourself into an observing position high up is important. The first is that you can look to the horizons. Such a technique will help you find the planet Mercury, which is mostly hidden in the Sun's glare. The second reason for elevation is the clarity of the night sky. If you stargaze from a high-altitude area you're above the densest portion of Earth's atmosphere, which causes atmospheric refraction, and so distortion. From a mountainous area stars don't twinkle, they glow, which is why the major astronomical observatories are in high-altitude areas such as Chile, Hawaii and the Canary Islands.

PLAN AHEAD

5 Are you missing a big night-sky event such as a meteor shower, planetary conjunction or even a lunar eclipse? Find an astronomy calendar online and you can discover the key dates for major events in the night sky. If you know the dates of forthcoming meteor showers, plan to stargaze during them and you'll hopefully catch a shooting star or two. Also keep an eye on the movements of the planets, especially their date of 'opposition', when a planet comes into opposition, Earth is precisely between the Sun and that planet, so it shines more brightly. The same goes for planetary conjunctions. When two planets appear to be close to each other in the night sky, find out the date and make a plan to stargaze.

You should also plan ahead more generally. For example, if you want to point a telescope at a faint fuzzy object, such as a galaxy or nebula, find out when it will be at the zenith, directly above your head. That's the darkest part of the sky, so the best place to observe it.

GET TO KNOW THE MOON

6 Can you pick out the major features on the Moon? Many a stargazer has been distracted by the Moon, and it may even be why you got hooked on the night sky to begin with. Either way, it's worth getting to know its geography. The best time to Moon-watch is the first week after new Moon, between its waxing crescent and first quarter phases. Night after night you can watch the Moon's surface slowly being revealed to you, from major craters Tycho, Copernicus and Aristarchus to the dark-grey lava plains such as the Sea of Serenity, the Sea of Tranquillity and the Sea of Fertility. It may also be of interest to be able to identify where man walked on the Moon during the Apollo missions. With binoculars you can easily see the general location of Moltke Crater and the nearby 'Tranquillity Base' in the Sea of Tranquillity where Apollo 11 astronauts Neil Armstrong and Buzz Aldrin walked on 20 July 1969.

FIND PLANETS QUICKLY

7 Finding 'wandering stars' should be difficult, and most people think that planets can be seen at any time and in any position in the night sky. After all, planets are always moving as they orbit the Sun at different speeds. In fact, it's easy to find planets because there's a line going from east to west across the night sky on which all planets are found. This is the ecliptic, and it's the path the Sun takes across the daytime sky. Note where sunrise and sunset take place, and have a rough idea of where the Sun is at noon, and you've got it. The ecliptic is nothing short of the flat plane of the Solar System, which stargazers get to see side-on, and it's here – and only here – that you'll see planets during darkness. Don't look to the north, or directly above, and speculate whether a bright star could be a planet. It's way simpler than that.

REHEARSE AND RELOCATE

8 How can you possibly remember the names of the 5,000 or so visible stars in the night sky? The truth is you can't, but you can learn to navigate the night sky quite easily. It's all about getting into good habits. When you step outside into the darkness at your usual stargazing location – most likely your back garden – take a few minutes to identify major constellations and bright stars that are easily visible to you. At the beginning of your learning you might pick out the Big Dipper one week, the Big Dipper and Cassiopeia the next week and in the third week use both of those constellations to find Polaris, the North Star. Even when you're semi-experienced in stargazing rehearsing what you already know is useful, particularly when done in a new location or somewhere you do not usually observe from.

DRESS PROPERLY AND EAT WELL

9 Hikers and outdoor adventurers spend incredible amounts of money on clothing and equipment to keep themselves warm. However, they're moving around a lot so producing their own heat. In contrast, stargazing doesn't involve much moving. This can mean you can get very cold, especially in winter when even the thought of going outside to look at the stars can send shivers down your spine. A hat and scarf/neck warmer are essential, and make sure to take a hot drink and snacks.

DARK-ADAPT YOUR EYES

10 Stand somewhere completely dark for a period of time and your pupils will dilate to let in as much light as possible. That way you'll see far more stars, and you'll have a chance of seeing the Milky Way. For stargazing and astronomy, dark-adapting your eyes is essential and will happen after about 20 minutes. Remember to take a red-light torch outside with you – any other kind of light will instantly kill your night vision.

UNDERSTAND YOUR EYES

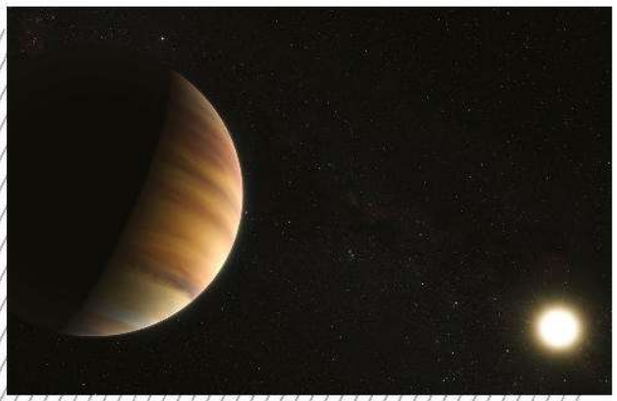
11 Perhaps the most important technique for effective observing is averted vision. It's based on the fact that the human eye's peripheral vision is the most sensitive to brightness, whereas its centre is more sensitive to colour. If you're observing star clusters, galaxies and nebulae – objects with incredible collective brightness – with the naked eye or through binoculars, look slightly to the left or right of the object. That way your eyes will better detect its brightness. This works well for objects like the Pleiades star cluster, the Orion Nebula and the Andromeda Galaxy. The same technique works in a slightly different way if you're using a telescope: if your left eye is to the eyepiece, look slightly to the left of the object, and vice versa. You can also look slightly above and below.

FIND THE ISS

12 Stargazing can also be about observing man-made objects orbiting our planet. Easily the most impressive is the International Space Station (ISS), which orbits Earth 16 times each day and travels faster than a bullet around 402 kilometres (250 miles) up. If you want to see the ISS from where you are, consult NASA's **spotthestation.nasa.gov** website to get exact timings. Transits take around four minutes, always generally from west to east, and always in the few hours after sunset or before sunrise, when the Sun catches the ISS' solar panels, which is what you actually see. Since the ISS only takes 90 minutes to orbit the planet, if you do see it just after dark there's a good chance you'll see it again 90 minutes later further to the north in the night sky. The ISS is so bright and so impressive an observing target that it will quickly become a staple of your stargazing.

USE YOUR MIND'S EYE

13 There's more to the night sky then you can see. With the naked eye you're only penetrating that first layer of the night sky: visible stars, clusters and the occasional galaxy. Even with binoculars or a telescope there's only so much you can see. But the news is full of new astronomical discoveries. Can you find them in the night sky? For example, most exoplanets found by astronomers using the Kepler space telescope are in two tiny patches of sky around the constellations of Lyra and Cygnus. Here's another: the first exoplanet ever discovered in 1995 was 51 Pegasi b in the constellation of Pegasus. It's about halfway between the bright stars Scheat and Markab. Halley's Comet? It's in front of the constellation of Hydra, close to bright star Sirius. Marry together what you observe with what you hear about in the news and not only will you get a deeper understanding of the night sky, but you'll also be able to navigate it on a whole new level.



IDENTIFY A NEW CONSTELLATION

14 You probably focus on constellations fairly high up in the sky, where stars appear brighter and are easier to identify. Constellations low on the horizon can be harder. Those rising in the east can be viewed later on when higher and easier to see. Get to know the 13 zodiacal constellations which lie across the celestial equator. Taurus, Gemini, Cancer and Leo are easy to find; Aries, Virgo, Libra, Scorpius, Sagittarius, Capricorn, Aquarius, Pisces and the 'forgotten' Ophiuchus can be tricky to identify. They're relatively low on the southern horizon and some of their stars are hard to find. Persevere – the fainter and more complex the constellation the more joy you'll get from finding it.

GET SOME GOOD BINOCULARS

15 The sky comes in three layers: the first is everything you can see with the naked eye and the third is what you can see with a telescope, but don't forget the second layer, which you can only really appreciate with a good pair of binoculars. They are portable and give you a stereo view of the heavens and a much wider field of view than a telescope. Binoculars are the only way to look at some objects in the night sky.

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WHAT'S IN THE SKY?

What to look out for during this observing period

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Red-light friendly

In order to preserve your night vision, you should read our observing guide under red light

7 OCTOBER
Mercury is at dichotomy, where it will reach half phase in the sky

8 OCTOBER
Mercury is at greatest elongation west, dazzling at -0.6 in the dawn sky

8 OCTOBER
The Moon and Jupiter make a close approach, passing within 1°50' of each other in Pisces

8 OCTOBER
The Draconid meteor shower reaches its peak

9 OCTOBER
Mercury reaches its highest altitude in the dawn sky

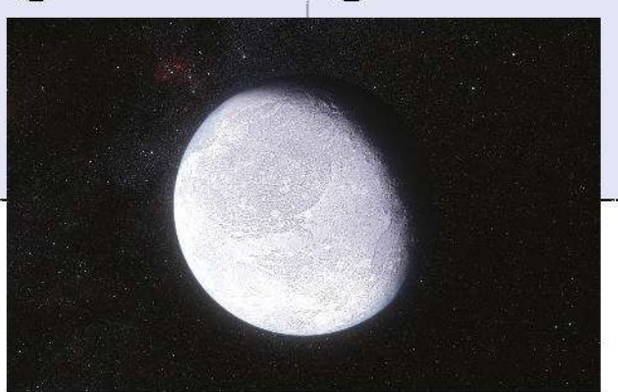
10 OCTOBER
The Southern Taurid meteor shower reaches its peak

11 OCTOBER
The Delta Aurigid meteor shower reaches its peak

12 OCTOBER
The Moon will pass in front of Uranus, creating a lunar occultation visible from parts of the Americas

15 OCTOBER
The Moon and Mars make a close approach, passing within 3°35' of each other in Taurus

15 OCTOBER
Messier 33 is well placed for observation at magnitude +6.3 in Triangulum



18 OCTOBER
Dwarf planet Eris reaches opposition in Cetus, glowing at magnitude +18.7

21 OCTOBER
The Orionid meteor shower reaches its peak

27 OCTOBER
Open star cluster NGC 884 is well placed for observation in Perseus at +6.1

Naked eye | Naked eye warning (TAKE CARE!) | Binoculars | Small telescope | Medium telescope | Large telescope | Solar eclipse | Solstice

18 OCTOBER
The Epsilon Geminid meteor shower reaches its peak

"Mercury is at dichotomy, where it will reach half phase in the sky"

24 OCTOBER
The Leonis Minorid meteor shower reaches its peak

25 OCTOBER
Partial solar eclipse visible from Africa, Asia, Europe, Greenland and Guernsey

26 OCTOBER
Open star cluster NGC 869 is well placed for observation in Perseus at +5.3

30 OCTOBER
Mars enters retrograde motion in Taurus, shining at magnitude -1.2

1 NOVEMBER
The Moon and Saturn make a close approach, within 3°58' of each other in Capricornus

4 NOVEMBER
The Moon and Saturn make a close approach, within 2°07' of each other in Pisces

Jargon buster

Conjunction
An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)
How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition
When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)
RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis, we see different parts of the sky throughout the night.

Magnitude
An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of -1.0 is brighter than +2.0.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© ESO; Getty;

PLANETARIUM

21 OCTOBER 2022

OPPOSITION

EVENING SKY

MOON CALENDAR

* The Moon does not pass the meridian on 8 October

7 OCT	8 OCT	9 OCT	10 OCT
95.3%	--.--%*	FM 98.9%	99.9%
03:36 18:01	05:00 18:15	06:22 18:28	07:43 18:42

11 OCT	12 OCT	13 OCT	14 OCT	15 OCT	16 OCT	17 OCT
98.4%	94.7%	89.0%	81.8%	73.4%	64.3%	TQ 54.7%
09:02 18:57	10:21 19:15	11:38 19:38	12:51 20:09	13:56 20:49	14:50 21:42	15:32 22:44

18 OCT	19 OCT	20 OCT	21 OCT	22 OCT	23 OCT	24 OCT
44.9%	35.3%	26.1%	17.7%	10.5%	4.8%	1.2%
16:03 23:54	16:26 --:--	01:06 16:44	02:21 16:58	03:36 17:11	04:51 17:24	06:09 17:36

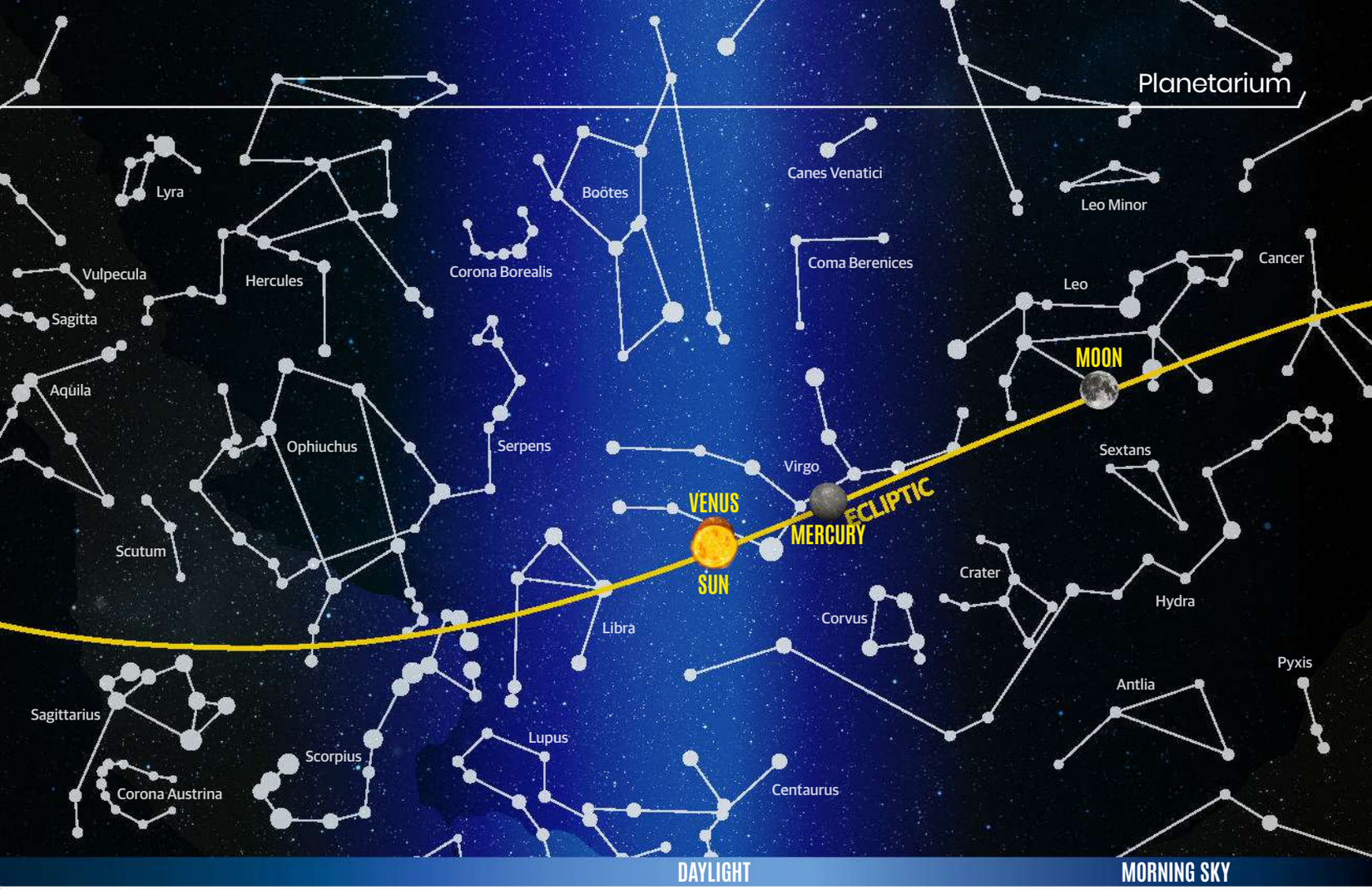
25 OCT	26 OCT	27 OCT	28 OCT	29 OCT	30 OCT	31 OCT
NM 0.0%	1.5%	5.7%	12.5%	21.6%	32.3%	43.9%
07:30 17:51	08:55 18:09	10:22 18:33	11:49 19:08	13:08 19:58	13:12 20:06	13:57 21:57

1 NOV	2 NOV	3 NOV	4 NOV
FQ 55.8%	67.2%	77.5%	86.2%
14:29 22:53	14:51 --:--	00:20 15:09	01:43 15:23

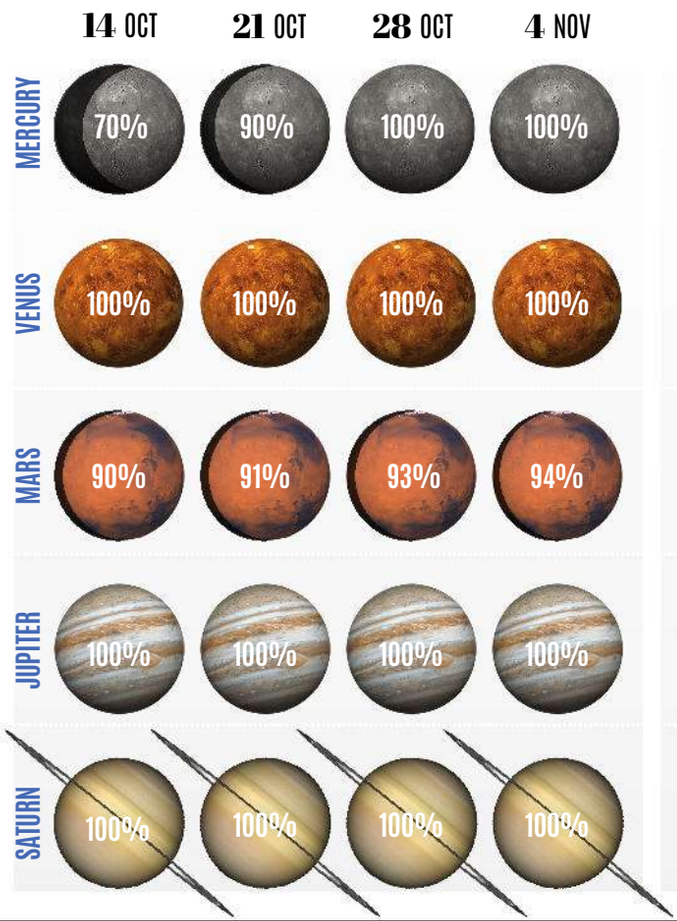
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

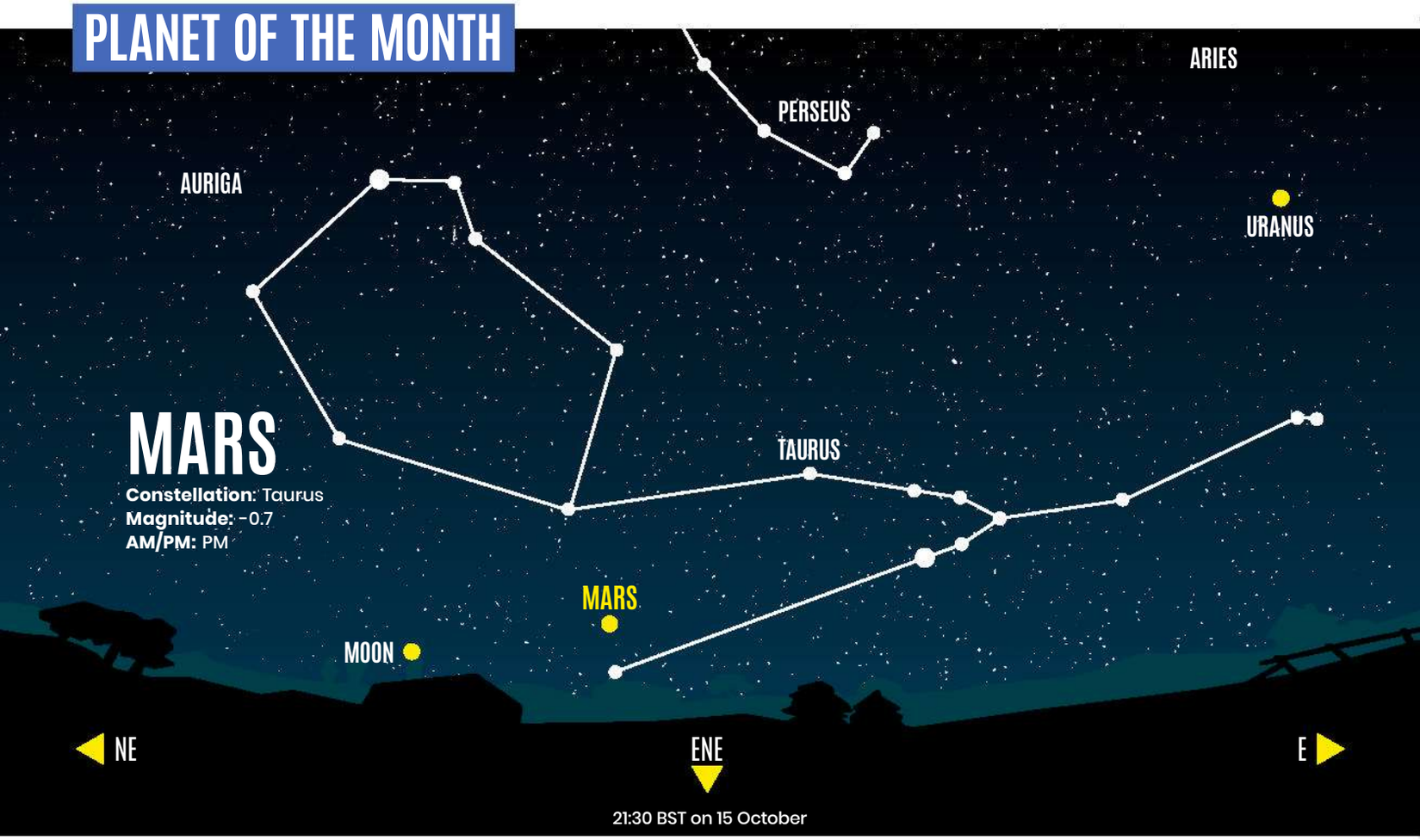
All rise and set times are given in BST/GMT

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
7 OCT	11h 46m 00s	+02° 47' 55"	Virgo	-0.3	05:24	17:59
14 OCT	12h 16m 46s	+00° 18' 41"	Virgo	-0.9	05:39	17:50
21 OCT	12h 57m 34s	-04° 06 '53"	Virgo	-1.0	06:15	17:41
28 OCT	13h 40m 51s	-09° 01' 11"	Virgo	-1.1	06:56	17:31
4 NOV	14h 24m 31s	-13° 41' 13"	Libra	-1.3	06:37	16:22
7 OCT	12h 36m 11s	-02° 24' 52"	Virgo	-3.9	06:40	18:23
14 OCT	13h 08m 21s	-05° 54' 04"	Virgo	-3.9	07:02	18:10
21 OCT	13h 40m 57s	-09° 17' 30"	Virgo	-3.9	07:25	17:58
28 OCT	14h 14m 11s	-12° 30' 45"	Virgo	-3.9	07:48	17:46
4 NOV	14h 48m 14s	-15° 29' 12"	Libra	-3.9	07:11	16:36
7 OCT	05h 23m 50s	+22° 42' 42"	Taurus	-0.7	21:09	13:32
14 OCT	05h 31m 28s	+23° 02' 45"	Taurus	-0.8	20:47	13:15
21 OCT	05h 36m 43s	+23° 21' 51"	Taurus	-1.0	20:22	12:55
28 OCT	05h 39m 15s	+23° 40' 46"	Taurus	-1.1	19:55	12:32
4 NOV	05h 38m 47s	+23° 59' 50"	Taurus	-1.3	18:24	11:06
7 OCT	00h 10m 02s	-00° 40' 29"	Pisces	-2.9	18:07	06:08
14 OCT	00h 06m 49s	-01° 00' 36"	Pisces	-2.9	17:34	05:32
21 OCT	00h 03m 55s	-01° 18' 28"	Pisces	-2.9	17:06	05:00
28 OCT	00h 01m 24s	-01° 33' 27"	Pisces	-2.8	16:37	04:28
4 NOV	23h 59m 23s	-01° 44' 59"	Pisces	-2.8	15:08	02:58
7 OCT	21h 25m 23s	-16° 31' 54"	Capricornus	+0.5	16:43	01:56
14 OCT	21h 24m 47s	-16° 34' 21"	Capricornus	+0.6	16:15	01:28
21 OCT	21h 24m 31s	-16° 35' 15"	Capricornus	+0.6	15:48	01:00
28 OCT	21h 24m 34s	-16° 34' 34"	Capricornus	+0.6	15:20	00:32
4 NOV	21h 24m 58s	-16° 32' 17"	Capricornus	+0.7	13:53	23:05

THIS MONTH'S PLANETS

Mars takes pride of place in the evening sky alongside the majority of its neighbouring Solar System planets

PLANET OF THE MONTH



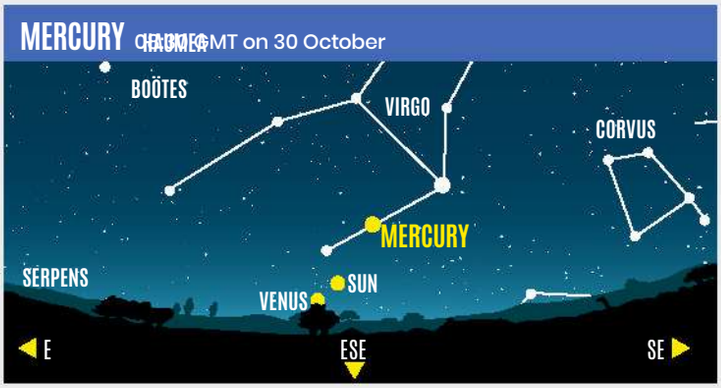
Mars is always visible to the naked eye when it's in the night sky, looking like an orange star, but sometimes it can become so bright it outshines every star and every other planet except Venus. This happens roughly every two years when it's at the closest point to Earth in its orbit. It will happen this December, when Mars will reach opposition. At the start of October, however, Mars will be a bright star shining to the left of the V-shaped Hyades star cluster. It will rise at around 21:00, then spend the night arcing across the sky from east to west before fading from view by sunrise.

As the days of October pass, Mars will slowly move away from the Hyades, brightening steadily as it goes, making it increasingly attractive to the naked eye. Although Mars will be a lovely sight in its own right, look out for a beautiful waning gibbous Moon shining just three degrees above it on the evening of 15 October. The camera on your phone should be good enough to capture this celestial pairing. By 1 November Mars will be shining at magnitude -1.2, making it almost as bright as Sirius, the brightest star in the sky. Still in Taurus, Mars will now be rising in the early evening and will be moving back towards the Hyades and Pleiades clusters again, growing ever brighter as it approaches opposition.

On 1 December, Mars will be at its very closest to Earth, just 81.5 million kilometres (50.6 million miles) away. That's a long way in terrestrial terms, but it's very close astronomically. At that distance the light from Mars will take only four-and-a-half minutes to reach Earth.

On the day of its closest approach, Mars will be a very obvious sight in the sky, a striking orange star of magnitude -1.8. It will rise as the Sun is setting, directly opposite it in the sky, and will be visible all through the night. Although it will be a lovely sight to the naked eye, it will look even more stunning in binoculars – both its brightness and colour will be greatly enhanced magnified even just ten times. But if you have a small telescope you'll be able to see Mars' ochre disc quite clearly. In moments of good seeing, when the air is still, the Red Planet's polar cap and dark features on its dusky surface will pop into view.

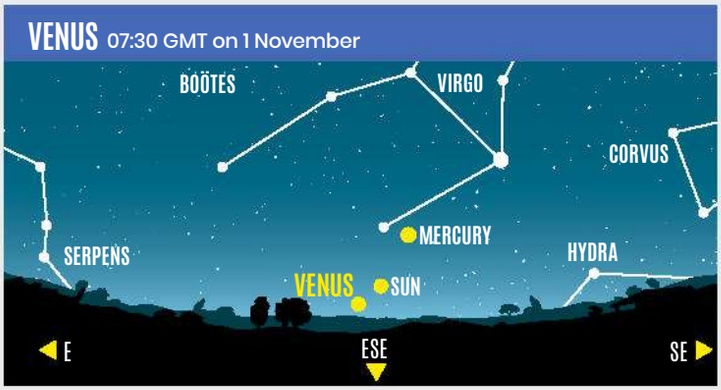
MERCURY 07:30 GMT on 30 October



Constellation: Virgo **Magnitude:** 0.0 **AM/PM:** AM

At the start of October, Mercury will be a bright naked-eye 'star' shining in the east before sunrise. It will rise around two hours before the Sun, so this will be a great time to see it. By 1 November Mercury will have lost a lot of height. It will rise only 20 minutes before the Sun, so despite having a magnitude of -1.2 it will be much harder to see.

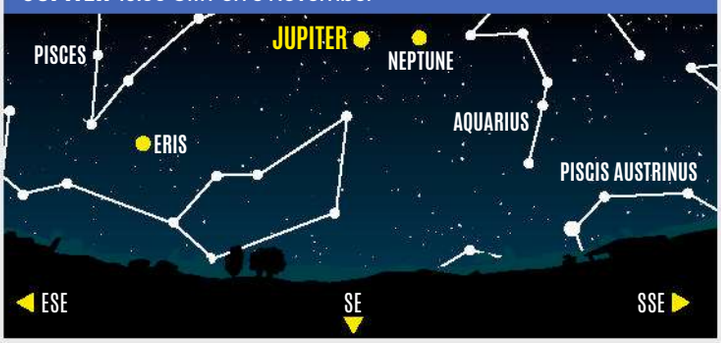
VENUS 07:30 GMT on 1 November



Constellation: Virgo **Magnitude:** -3.9 **AM/PM:** AM

In early October Venus will be a bright morning star, shining close to Mercury in the predawn sky, but the planet rises so shortly before the Sun that it will be hard to see. By 1 November Venus will be an evening star again, but will still be so close to the Sun that it will be hard to see in its glare.

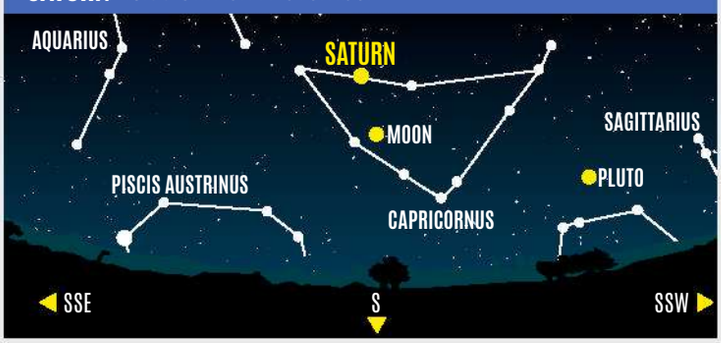
JUPITER 19:00 GMT on 3 November



Constellation: Pisces **Magnitude:** -2.9 **AM/PM:** PM

At the start of October, Jupiter will be visible low in the east as soon as twilight falls, nine degrees to the east of much fainter Neptune. By 1 November Jupiter will have faded very slightly to magnitude -2.8, but it will still be visible from sunset onwards. On the evening of 4 November, look for the Moon shining to its lower right.

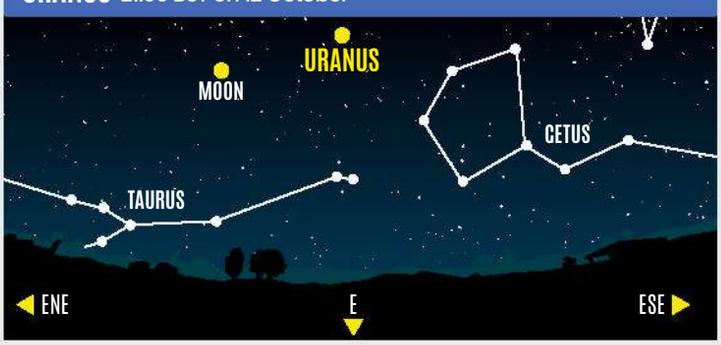
SATURN 19:00 GMT on 1 November



Constellation: Capricornus **Magnitude:** +0.5 **AM/PM:** PM

At the start of October Saturn will be quite high in the southeast after sunset, a naked eye 'star' with a yellowish hue. It will become more obvious as twilight deepens. By 1 November it will have decreased in brightness slightly to +0.7, but it will still be clearly visible to the naked eye, and its warm golden hue will be obvious in binoculars.

URANUS 21:00 BST on 12 October



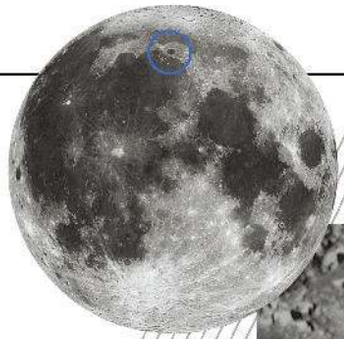
Constellation: Aries **Magnitude:** +5.7 **AM/PM:** PM

Uranus will be a faint evening star in the constellation of Aries. With a magnitude of less than +6.0 it will technically be visible to the naked eye, but only if you know exactly where to look for it. You will almost certainly need a pair of binoculars to pick it out from all the many equally faint stars around it.

NEPTUNE 21:00 BST on 12 October

Constellation: Aquarius **Magnitude:** +7.8 **AM/PM:** PM

Neptune never becomes bright enough to see without binoculars or a telescope, and at the start of October it will be a very faint 'star' in Aquarius, just nine degrees away from much brighter Jupiter. By 1 November Neptune will still be found close to Jupiter, but the distance between them will have shrunk to less than seven degrees.



MOON TOUR

MONS PICO

Explore one of the most isolated mountains on the lunar surface

The ancient light-and-dark-dappled surface of the Moon is dominated by three types of geological features: craters, seas and mountains. Look at the Moon through a telescope – even a small one – and you'll see mountains everywhere. Some stand alone on the edge or in the middle of one of the maria, the dark seas of frozen lava, while others form long ranges that curve across the seas like the long-buried fossilised spines of dinosaurs being eroded from the rock. Others still form the jagged rims of its craters.

Our Moon tour destination this month is a smaller, much less imposing mountain to the north of the Moon. Mons Pico – or Mount Pico – is a small nub of a mountain, 25 kilometres (15.5 miles) long, 15 kilometres (9.3 miles) wide and 2.4 kilometres (1.5 miles) in height, which sounds impressive, but Pico isn't as high as even the hundredth-tallest mountain on Earth. In fact, it's only around the same height as Mount St Helens, the American volcano that famously blew its top in May of 1980.

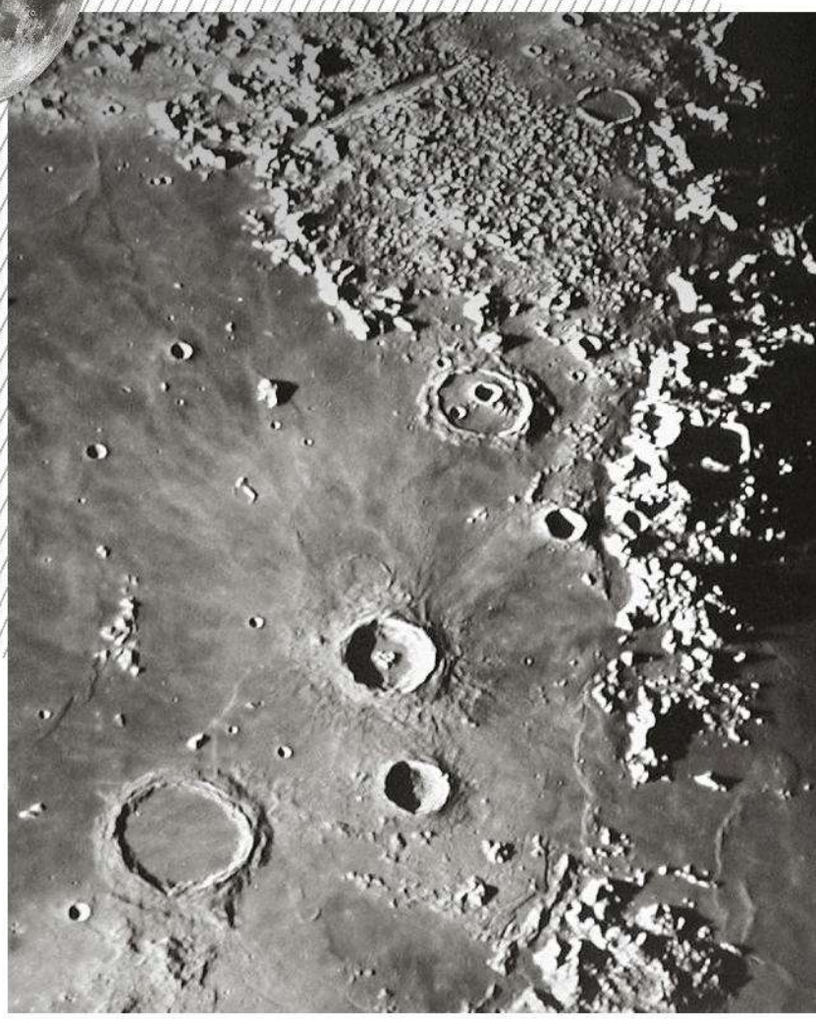
Clearly it's not Pico's height that makes it worth seeking out. It's the mountain's isolation. Mons Pico can be found in the far north of the huge Mare Imbrium basin, a short distance to the south of the famous dark-floored crater Plato. It stands out, and thus is so easy to find, because there really isn't much else around it. To the northwest is a small V-shaped range of much smaller peaks, the Tenerife Mountains, and directly north of Pico is a short chain of craters that look like holes left in an antique table by woodworm, but they're so tiny you'll need very high magnification to see them.

Pico might not be as high as other lunar mountains, but just like its taller relations it casts a shadow. When the terminator – the line between lunar night and day – is nearby, that shadow can be very striking, making Pico stand out very clearly from the dark, rolling plain of Mare Imbrium. At full Moon, with the Sun straight overhead and all surface relief banished by the harsh glare, the mountain is reduced to a bright spot, as white as a dot of correction fluid on paper. Conversely, when sunlight strikes Mons Pico at a shallow angle the mountain casts a shark tooth of shadow that makes it stand out starkly, even at low magnification through a small telescope.

Mons Pico might not be well known to casual observers of the Moon, but it is to science-fiction fans and space-exploration enthusiasts. Iconic space artist Chesley Bonestell painted the mountain several times in the pre-Apollo years; it features in the groundbreaking 1949 book *The Conquest of Space* and also in one of his illustrations for the A Trip to the Moon feature in the 1946 issue of *Life* magazine. And fans of Arthur C Clarke's Odyssey series will recognise Mons Pico as the site of humanity's repository of biological and computer viruses.

So when can you see Mons Pico this month for yourself? As luck would have it, Mons Pico is well placed for observation at the start of our observing period. On 6 October the terminator will have just swept over the mountain and it will be a striking feature, looking like a sharp piece of bone sticking out of the Moon with a dark shadow cast behind it to the west. For the next few days it will be bathed in more and more sunlight. The shadow will gradually shrink back to the foot of the mountain until full Moon on 9 October, when Mons Pico will look like a white dot beneath the dark blue-grey circle of Plato.

By 13 October Mons Pico will begin to become more apparent again as the terminator creeps back over it – this time from the other direction. By now the Moon will be at its waning gibbous phase in the predawn sky, so seeing Mons Pico emerging from the darkness will mean having to get up early, but as you look at it you'll be able to see Mars, now very bright, in the same area of the sky.



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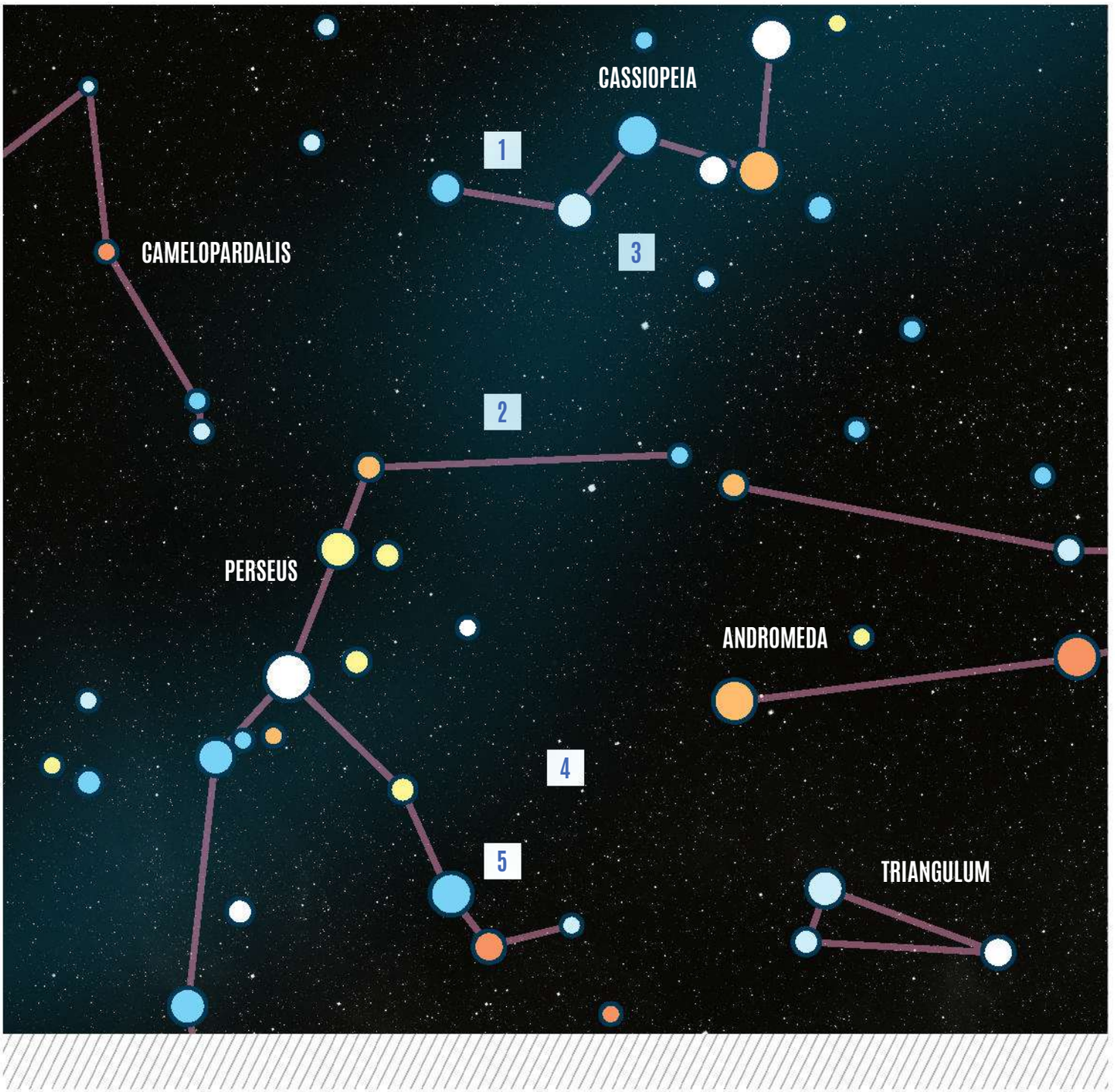
TOP TIP!

As with other lunar features, you'll enjoy your best view of Mons Pico when it's close to the terminator.



NAKED EYE AND BINOCULAR TARGETS

The skies are rich with objects sure to delight any observer

1 The 'W' of Cassiopeia
The five main stars that make up Cassiopeia are instantly recognisable. This is one of the oldest constellations known.

2 The Double Cluster
Visible in 10x50 binoculars, the Double Cluster is the jewelled handle of Perseus' sword and is teeming with resolvable stars.

3 The Owl Cluster
Two bright stars make up the owl's eyes, which are best seen in binoculars. This cluster is also known as the Dragonfly Cluster.

4 The Spiral Cluster
Otherwise known as Messier 34, this star cluster is just visible to the naked eye. 10x50 binoculars will reveal its twisted structure.

5 Algol
An eclipsing binary star that dips in brightness every 2.86 days, its blue-white appearance is obvious to the naked eye.

2 Crab Nebula (Messier 1)

DEEP SKY CHALLENGE

THE BULL AND CHARIOTEER'S DEEP-SKY WONDERS

In late autumn, the constellations of Taurus and Auriga are packed with objects for telescope owners

The constellations of Taurus and Auriga are a rich hunting ground full of star clusters and nebulae to delight any telescope user. Quite apart from the famous open star cluster of the Pleiades, which is great to explore with a telescope of any size, there are other clusters that are equally rewarding. There are nebulae, too, perhaps the most famous of these being the Crab Nebula, which was the first object on Charles Messier's well-known list.

Head into the constellation of Auriga, which is attached to Taurus by the blue-white star Elnath, or Beta Tauri, and you'll discover a chain of impressive star clusters and the Flaming Star Nebula, designated IC 405. This is a fascinating region of the sky and well worth exploring with a telescope. We hope you enjoy your exploration of the deep sky – here are a selection of objects for you to observe with your instrument, whether it has a small, medium or large aperture.

1 Hind's Variable Nebula (NGC 1555)

1 Hind's Variable Nebula (NGC 1555)
NGC 1555 is an intriguing object which varies in brightness, as does the star that illuminates it.

2 Crab Nebula (Messier 1)
This is a supernova remnant – the matter left over after a star explodes. The stellar eruption was initially recorded in 1054 in China.

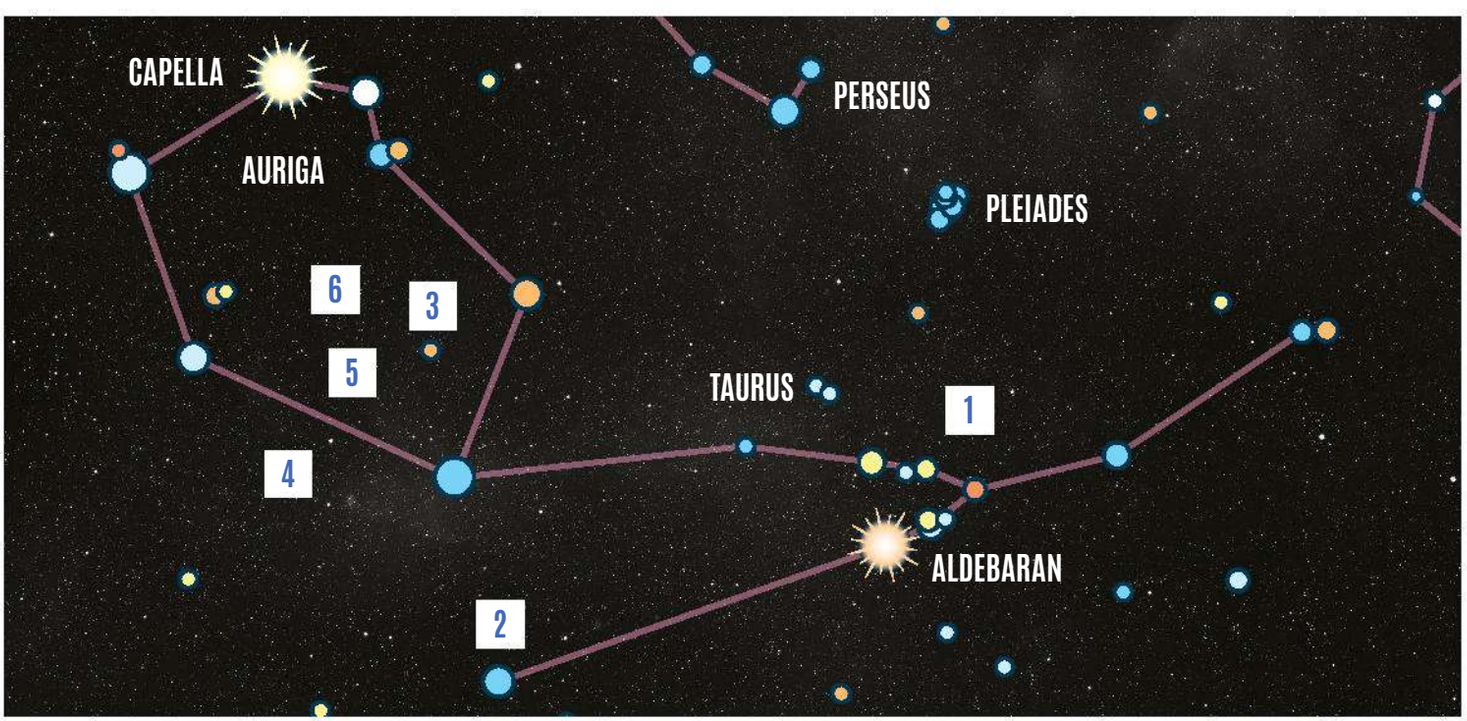
3 Flaming Star Nebula (IC 405)
Containing both an emission and a reflection nebula, this object covers an area of sky about the size of the full Moon.

4 Messier 37
The brightest of the three star clusters in the constellation of Auriga, Messier 37 can be resolved at medium power in a small telescope.

5 Messier 36
Although not as impressive as Messier 37, a small telescope at low power will reveal the member stars of this open star cluster.

6 Messier 38
Open star cluster Messier 38 is the faintest of the three clusters in this region. It's also known as the Starfish Cluster.

3 Flaming Star Nebula (IC 405)

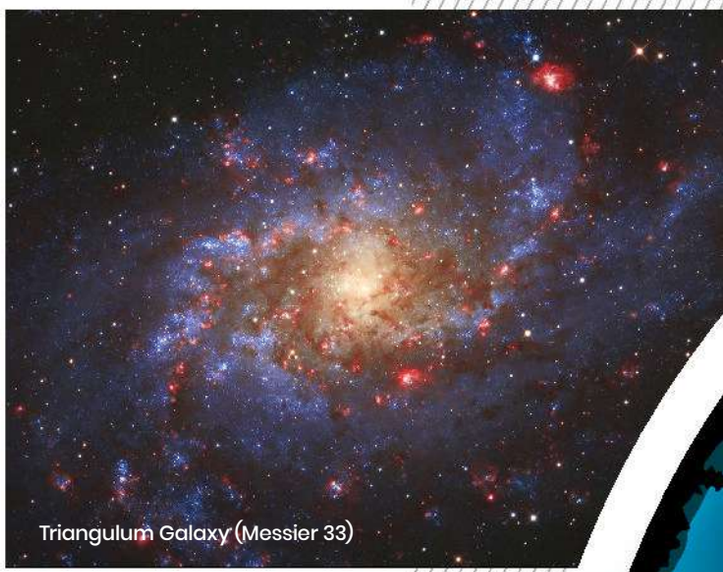


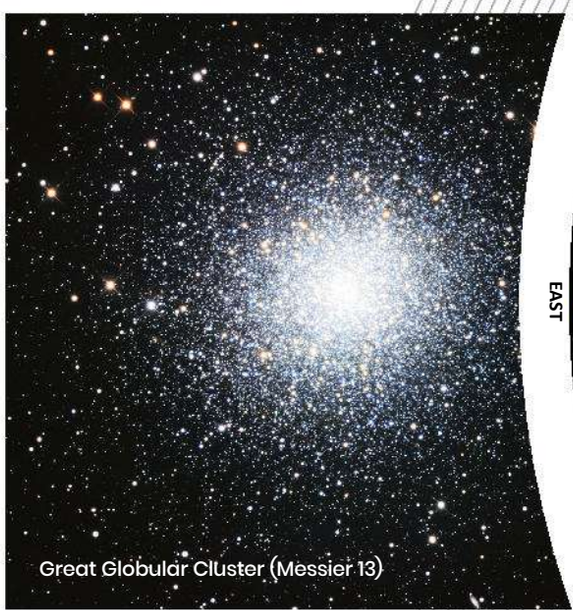
© NASA; ESA; J. Hester; A. Loll (Arizona State University); Adam Block; Mount Lemmon SkyCenter; University of Arizona

THE NORTHERN HEMISPHERE

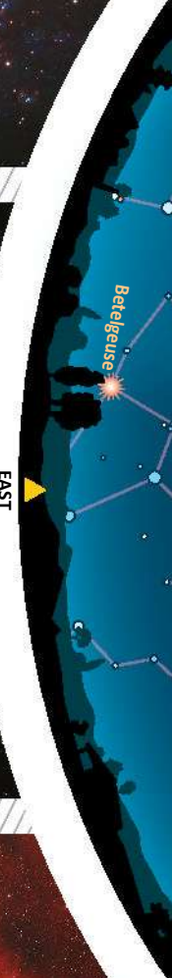
You no longer need to stay up late to enjoy a whole host of night-sky objects

Autumn provides a stunning selection of open and globular star clusters, galaxies and a smattering of nebulae. By mid-October the Sun will be setting by 18:15, meaning observers no longer need to stay up until the early hours of the morning to make the most of what the night sky has to offer. If you have a telescope of at least a small to medium aperture, galaxies such as the circumpolar Fireworks Galaxy (NGC 6946) in the constellation of Cepheus and the ever-beautiful Andromeda Galaxy (Messier 31) in the constellation of Andromeda, as well as the nearby Triangulum Galaxy (Messier 33) in Triangulum, will make ideal targets. Before dawn, keen observers will be able to capture Messier 74 in Pisces and Messier 77 in Cetus.


Triangulum Galaxy (Messier 33)


Great Globular Cluster (Messier 13)

Elephant's Trunk Nebula (IC 1396)



Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

Magnitudes

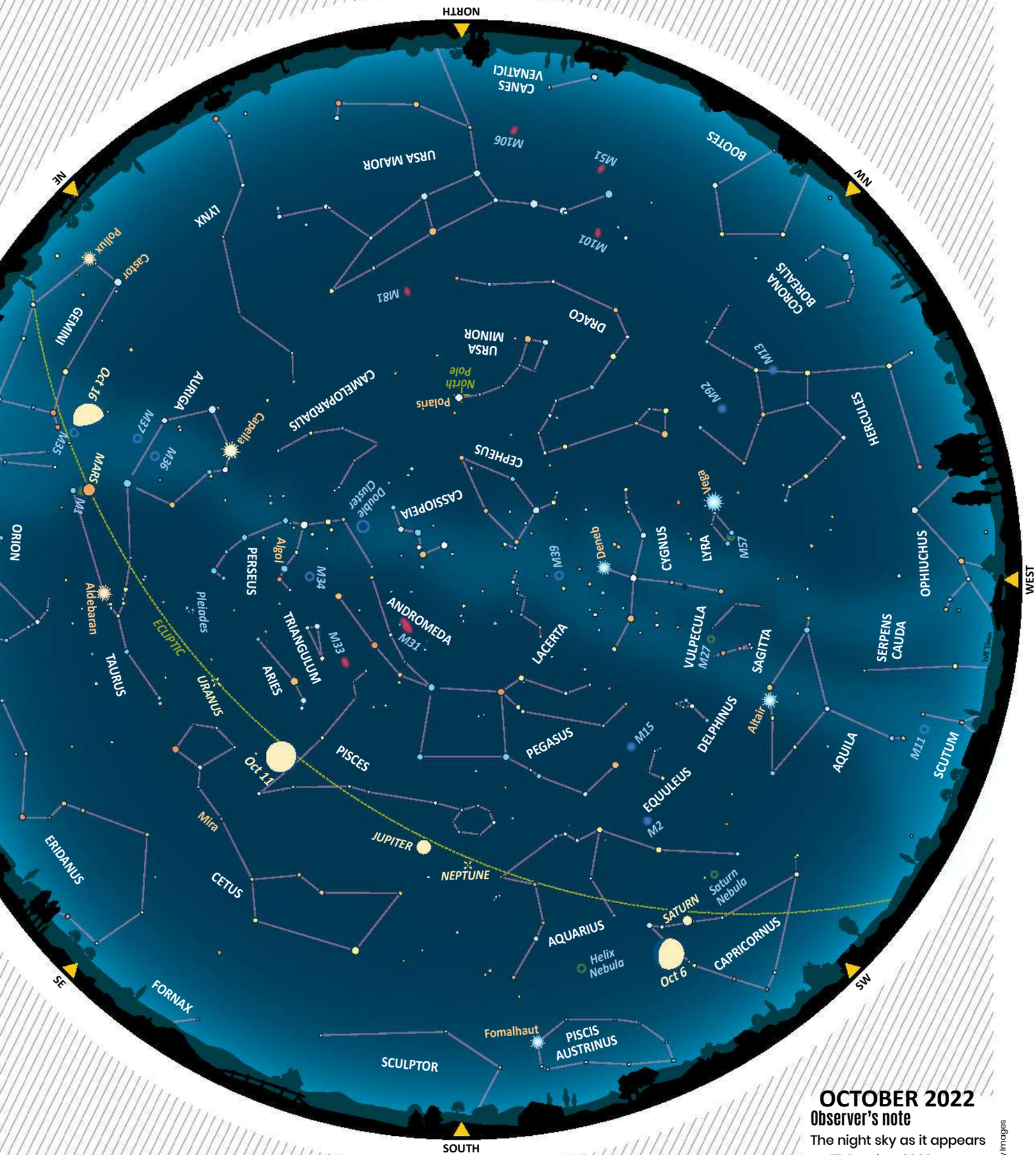
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O–B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



OCTOBER 2022

Observer's note

The night sky as it appears on 17 October 2022 at approximately 22:00 (BST)

© Getty Images

ASTROSHOTS OF THE MONTH

ANDREI PLESKATSEVICH

Location: Minsk, Belarus

Telescope: Askar FMA180

"Over the course of several months I imaged some of my favourite targets, the North America Nebula, Pelican Nebula, Flaming Skull Nebula and Spaghetti Nebula, using a ToupTek ATR3C571. The North America and Pelican nebulae can be found in the constellation of Cygnus, while the Flaming Skull is located in Serpens Cauda. The Spaghetti Nebula, a supernova remnant, straddles the border between the constellations Auriga and Taurus."

Spaghetti Nebula (Simeis 147)

FERNANDO MENEZES

Location: São Paulo, Brazil

Telescope: Sky-Watcher Esprit 150 ED PRO

"Over recent months I took great enjoyment in imaging the famous Southern Pinwheel Galaxy (Messier 83) using a ZWO ASI6200MC-PRO full-frame CMOS camera and compiled a coloured mosaic of our natural satellite, the Moon."

The Moon in colour

Antares, Jabbah, Acrab and Fang forming the Summer Triangle

SERGIO CONCEIÇAO

Location: Madeira, Portugal

"This shows a tree on Pico Ruivo on Madeira, almost at the highest point of 1,861 metres of altitude. The constellation formed by the pulsating variable star Antares, Jabbah, Acrab and Fang is visible. Antares is present with a more intense shine, and in yellowish tones, just to the right of the tree. A little further up it's possible to see the triangle formed by Jabbah, Acrab and Fang in bluish tones. In the background, with some light contamination from the island's artificial lighting, you can see the dyed clouds in yellowish tones. If it's already exciting to be above the clouds during the day, it's even more exciting to be above them at night in a completely dark place, imagining that under those clouds there is a world with things happening by the minute."

REVIEW

VAONIS STELLINA OBSERVATION STATION

A combination of telescope and camera, this instrument brings the universe to the palm of your hand in minutes

Reviewed by Robin Scagell

TELESCOPE ADVICE

Cost: £3,630 / $3,999

From: Vaonis

Aperture: 80mm f/5 ED refractor

Focal length: 1,200mm

Field of view: 1.0 by 0.7 degrees

Camera resolution: 6.4 megapixels

Eyepiece focal length: 25mm (48x)

Total kit weight: 11.7 kilograms

Mount type: Alt-azimuth

The Stellina is like no other telescope you've ever seen. At first glance it appears to be a smooth plastic box about the size of a small suitcase, and even when it's in operation there's no eyepiece to look through. This is a truly smart telescope, as revolutionary and different in design as when we compared the modern-day smartphone with a traditional landline telephone.

It is a purely astronomical imaging device, which might disappoint those eager to view the wonders of the heavens with their own eyes. Yet it will deliver images of objects that you could never hope to see visually in full colour and within a matter of minutes. It is restricted to astronomical objects and will not take images during the day or when no stars are visible.

The instrument is sleek and shiny, and to some extent belies its power to find and take images of a wide range of objects. It is quite weighty and not trivial to carry around, although the ads show it being backpacked by fit young men. There are no grip points or handles and the smooth casing is quite slippery, so you need to take care. However, it appears to be robust and we had no problems with the unit functioning after a car journey.

Unlike most amateur telescopes designed for imaging, the Stellina has a simple alt-azimuth mount, with up-down, left-right movements only, rather than the more complex equatorial mount that requires alignment with Earth's axis. This results in a rotation of the image which is compensated for internally, and by limiting exposures to only ten seconds each. The app then stacks these automatically, building up the total exposure time using many individual exposures.

A brief online video shows how to attach the separate short, stubby tripod and plug in the battery, which you need to charge separately using a standard AC charger for USB devices, which isn't supplied. The battery provides up to five hours of observation. Next, you download the control app to your phone or tablet. We encountered a slight problem here because the instructional video referred to an outdated app, Stellinapp, that no longer functions. The app now required is called Singularity.

No further instructions are provided other than in the app, which involves first creating an account while connected to the internet and then switching on the instrument. Although the stages of starting the instrument are straightforward, a sheet of step-by-step instructions would greatly simplify the matter. The Stellina creates its own Wi-Fi hotspot, so you can use it in any location, but bear in mind that you may lose your internet connection while using it.

We first tested the Stellina in suburban skies at latitude 51 degrees north in midsummer, with a bright Moon in the sky – less than ideal conditions. Even so, the results were impressive. Star clusters, nebulae and galaxies all appeared with satisfying quality, although the longer the exposure time the better the results. The same objects would be virtually invisible to the eye under the same conditions, even with a much larger telescope.

The unit has an in-built city light suppression (CLS) filter that leaves the images with no trace of light pollution. The colours in the nebulae and stars are represented accurately and the star images were usually of good quality, although not as sharp as one would like. Slight trailing was visible on some images, turning the pinpoint stars into short streaks.

You can add objects to the existing database, as long as you know their positions. We tried this on a comet well below naked-eye visibility, and a good image of the object appeared quickly. The scale of the images is not really suitable for planetary observing: you can view the belts of Jupiter and the rings of Saturn, but not get detailed photos of the planets themselves.

The only effort required from the user is to level the telescope using the built-in bubble level, connect to its hotspot and then press a button on the app to initialise the scope under a clear night sky. On doing this the telescope arm swings out and points upward to photograph a random area of stars, which it analyses and identifies. Then it goes through an automatic focusing procedure taking a minute or two. When ready, it asks you to choose a target.

Again, for a newcomer some guidance would be useful because although the app presents you with a range of objects currently visible, your first choice could be a disappointment if you overlook the recommended exposure time. So our advice is to choose an object that can be photographed with an exposure time of 15 or 30 minutes. The instrument then swings

The specially designed 48-litre Stellina backpack weighs 1.7 kilograms

It has separate compartments for the battery and tripod

BEST FOR...

- LARGE BUDGETS
- FAMILIES
- BEGINNERS
- ASTROPHOTOGRAPHY
- STAR CLUSTERS
- GALAXIES & NEBULAE

"The unit has an in-built city light suppression filter that leaves the images with no trace of light pollution"

The padded backpack protects your telescope

to its position, and within a few minutes images start to appear on your device. Even the first ten-second exposure may show a faint image of the target, and the ten-second exposures build up as you watch, gaining in quality all the time. You can save the pictures to the app gallery, your device or a USB memory stick in several formats for further image processing if you wish.

Once the instrument is up and running, it can be left to its own devices and you can retreat indoors if you want to. You can continue to view the results and choose new targets as long as you remain within the range of its hotspot, about ten metres. This is a great advantage on a chilly night. The Stellina will continue observing even if you are out of range. The lens is heated if the temperature drops, to avoid dewing up.

We noted some design niggles. The battery compartment is covered using a push-fit plate, which is then loose and, being black, is easily lost at a dark observing site. The 10,000 mAh battery is basically a USB power pack, and the only way to switch off the instrument is to remove the side plate and unplug it. An additional switch on the side of it would avoid awkward fiddling inside the cramped compartment. Gripping points would improve the ease of moving the instrument.

The Stellina's help files, both online and in the app, are in the form of questions and answers rather than being well structured, so beginners in particular may struggle to understand how to get the most from the instrument. Because the telescope is self-contained, with no user-serviceable parts, if anything does go wrong the instrument may have to be returned to the manufacturer in France for repair or updating.

"Even the first ten-second exposure may show a faint image of the target, and the ten-second exposures build up as you watch"

The price will put many people off, but you are paying for the convenience and ease of use. You can get equivalent or better results for considerably less money using conventional telescopes and cameras but you'll need much more expertise. Alternatively, for the same amount you can build a much more versatile and powerful system that you can also look through. But while you are struggling to connect everything and get some results, the Vaonis Stellina will probably have taken several images, so it's all a matter of your priorities and interests.

FOR

- ⊕ Fully automatic operation from app
- ⊕ Easy to use
- ⊕ Attractive images even with light pollution

AGAINST

- ⊖ Very expensive
- ⊖ Not suitable for observing planets
- ⊖ Not widely serviceable
- ⊖ Poor instructions

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IN THE SHOPS: STAR PROJECTORS

Our round-up of the best star projectors on the market right now

3

1

2

Sega Toys Homestar Flux

Cost: £169 / $259
From: Sega Toys

1 One of the sleekest-looking and most powerful star projectors around, the Homestar Flux, though compact, comes with a high price. More of a home planetarium than a simple star projector, we found that the Flux's multilevel glass lenses produce realistic-looking night skies from the comfort of your own home – it's also bright enough for rooms that aren't totally dark. After adjusting the focus to suit your projection surface, you'll see 60,000 stars – many more than its competitors. This globe-shaped product excels with the sheer number of distinct stars it projects, and it has some tempting science-based upgrade options. The Flux comes with two discs: the Northern Hemisphere and the Northern Hemisphere Constellations. One shows a starry sky with 60,000 stars, while the second contains constellation labels to aid with learning. There are a further 17 Sega-branded discs available, though these are to be purchased separately.

Smithsonian Optics Room Planetarium and Dual Projector Science Kit

Cost: £118.64 / $135
From: Amazon

2 Shipping with an adjustable desktop stand, you can aim the projector wherever you like and see stars across the ceiling and walls. With the default planetarium slide you can make the stars rotate and move, using them either as the sole image or as a background to other images that come from three other slides in the box – 24 simple still images of objects ranging from the Sun, Earth, Moon, asteroids and planets, the International Space Station, Space Shuttle, an astronaut on a spacewalk and deep-sky sights such as galaxies and nebulae. It also includes an educational poster. It's something intended for a child rather than an adult. It shows only the stars of the Northern Hemisphere and lacks labels and constellation guidelines, so whether or not it's possible to learn anything from its projections is questionable.

National Geographic Astro Planetarium

Cost: £104.99 (approx. $120.85)
From: Bresser

3 The National Geographic Astro Planetarium is a high-quality indoor planetarium that accurately represents the night sky and comes with plenty of extras. Two projection discs are included: one shows 8,000 stars and the other overlays guidelines for the major constellations. What you see is true to the time and day you set it. The result is a bright and sharp projection on the ceiling. However, stars at the edge of the projection can seem blurry. An optional falling star mode projects a flashing 'meteor' every 40 seconds, though always in the same place. In the box are four educational posters, three AA batteries and a 3.5mm jack cable, the latter of which is to hook up a smartphone or other audio device to play through this star projector's small mono speaker. It also acts as an FM radio if you want to listen to music or soothing sounds while you stargaze indoors.

"This laser-powered galaxy projector takes viewers on a journey through multicoloured clouds"

Blisslights Sky Lite 2.0

Cost: £49.99 / $69.99
From: Blisslights

4 Imagine being immersed within a star cluster or drifting through a nebula. If you want scientific accuracy look elsewhere, for what you get with the Sky Lite 2.0 is a mesmerising ambient experience that makes up for in creativity what it lacks in scientific rigour. This laser-powered galaxy projector takes viewers on a journey through multicoloured clouds. We found it very easy to set up and liked its easy operation. It can be set to project at three different angles, including upwards onto a ceiling. It uses an LED and direct laser diode, which together create motion-filled RGB projections. Portability is further helped by a USB power cable, which means the Sky Lite 2.0 can be powered by a computer or from a portable battery. This latest 2.0 version also includes the BlissLights smartphone app, which lets the user connect via Bluetooth and choose from seven built-in effects modes, customise the projector's intensity, the brightness of the laser and the rotation speed.

Bresser Junior Astro Planetarium Deluxe

Cost: £87.99 (approx. $101.30)
From: Bresser

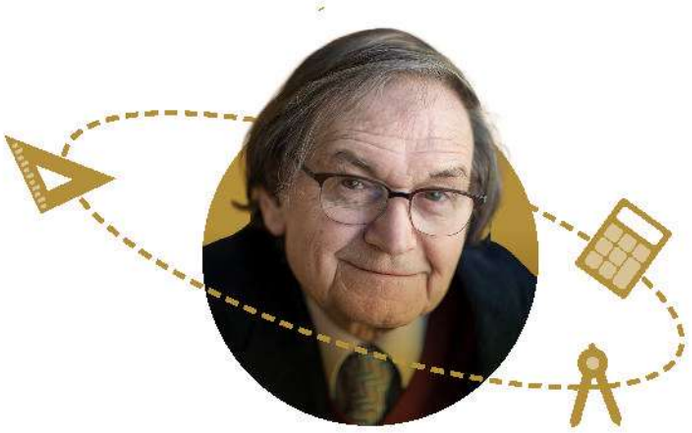
5 Though not as vibrant as Bresser's National Geographic Astro Planetarium, the Bresser Junior Astro Planetarium Deluxe is an almost identical product. This incarnation has the same essential specifications and projections and works in the same way, but there are some notable differences. The same Astro Planetarium Multimedia discs are included – one featuring a starry night sky and the other overlays of constellations, and it's all entirely accurate for the time and day you're using it. You can rotate the image through 360 degrees using its built-in motors and it's easy to adjust the image using a focusing wheel around the lens. It can be set to automatically shut down after 30, 60 or 120 minutes, which is useful if it's intended for a child's bedroom and they want to fall asleep under the stars. It's also got a falling star mode, which can be activated to project a 'meteor' every 40 seconds.

Omegon Star Theatre Pro Planetarium

Cost: $200 (approx. £173.80)
From: Omegon

6 Here's a star projector that is a more serious astronomical device than some, but only just. Shipping on a small tripod desktop stand, the Omegon is powered by a USB cable, which means it can be attached to any portable battery source – helpful if you want to place it in the centre of a room. The adjustable projection distance is handy, but although it illuminates the ceiling with a realistic night sky of 10,000 stars, it lacks brightness, ultimate sharpness and stellar accuracy. For example, you can't adjust it to be time and day specific, hence you're only getting a random starry night sky that lacks context, labels or constellation guides. It's tricky to find anything you might recognise, though it does include the arc of the Milky Way. It's suitable for anyone after a decorative night sky projection, but not necessarily effective as a learning device.

HEROES OF SPACE



ROGER PENROSE

His academic work changed and shaped the way we see the cosmos

After finishing his PhD in 1958, it was Penrose's work in the 1960s that brought him to prominence. In 1965 his paper *Gravitational Collapse and Space-Time Singularities* proved groundbreaking, establishing the existence of cosmological singularities in the framework of general relativity. It showed how continual gravitational collapse under the existence of a trapped surface gave rise to space-time singularities, and the work proved vital in showing how Albert Einstein's general theory of relativity implied space and time had a beginning in the Big Bang.

Penrose worked with Stephen Hawking on gravitational singularity theorems in relation to the cosmological Big Bang and developed ideas about black holes. His papers showed that mathematical singularities were an inevitable initial condition that could be explained by general relativity and that black holes were like a reverse Big Bang, which was revolutionary.

Penrose also had other ideas up his sleeve. He developed twistor theory with his associates, lending mathematical insight into theories that lay deep within the Standard Model of particle physics as he sought to unite relativity and quantum theory. In this, the relation between events in space-time is said to be vitally important, described using the geometry of twistor space. Penrose's 1967 paper has subsequently led to a proposed connection between string theory and twistor geometry. It's no surprise that Penrose's work has earned him a good number of prizes and awards. He was elected a fellow of the Royal Society of London in 1972 and a Foreign Associate of the US National Academy of Sciences in 1998. His contributions to our understanding of the universe were also recognised when he was knighted for his services to science in 1994.

He remains curious, constantly trying to address questions of potential higher dimensions of space and time and the origins of the universe itself. In 2010 Penrose claimed to have glimpsed the universe before the Big Bang, having studied data collected by NASA's Wilkinson Microwave Anisotropy Probe. This supported his idea of conformal cyclic cosmology – the thinking that the Big Bang was one of a series of cyclical big bangs. He believes our universe wasn't the first to have been born out of a highly ordered dense mass. Today, Penrose works on developing theories and pushing the frontiers of science in his role as the Emeritus Rouse Ball Professor of Mathematics at the University of Oxford.

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